California Regional Water Quality Control Board
Santa Ana Region

Staff Report on the Nutrient Total Maximum Daily Loads for Big Bear Lake

Prepared by:

Heather Boyd
Environmental Scientist
Inland Waters Planning Section

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EXECUTIVE SUMMARY

This document describes the proposed Total Maximum Daily Loads (TMDLs) for nutrients for Big Bear Lake. Section 303(d) of the Clean Water Act (CWA) requires States to identify waters that do not or are not expected to meet water quality standards (beneficial uses, water quality objectives and the state's antidegradation policy) with technology-based controls. The States are then required to develop a TMDL for each of the constituents listed on the 303(d) list. The TMDL establishes the maximum load of a pollutant that can enter the listed water body without violating water quality standards. A TMDL is defined as the sum of the individual wasteload allocations for point sources, load allocations for nonpoint sources including natural background, and a margin of safety. Seasonal variations and critical conditions must also be addressed. The Regional Board placed Big Bear Lake on the 303(d) list in 1994 due to excessive nutrients and noxious aquatic plants. Rathbun (Rathbone) Creek, Summit Creek, and Grout Creek, tributaries to Big Bear Lake, were also included on the 1994 list due to excessive nutrients. The listings were based on the historic information summarized in Section 2.2 and Appendix A. Excessive nutrients and sediment deposition in Big Bear Lake have contributed to the eutrophic condition of the lake. The proliferation of two aquatic plants, primarily Eurasian watermilfoil (*Myriophyllum spicatum* L.) and Coontail (*Ceratophyllum demersum* L.), severely impact the beneficial uses of Big Bear Lake, including water contact recreation (REC1), non-contact water recreation (REC2), warm (WARM) and cold (COLD) freshwater habitat and wildlife habitat (WILD). The nutrients addressed by the TMDLs are nitrogen and phosphorus.

Rathbun Creek, Summit Creek, and Grout Creek contributed the highest nutrient loads to Big Bear Lake in 1992 and 1993, which led to their placement on the 303(d) list in 1994. Since that time, the creeks have been monitored periodically. Since the start of the watershed monitoring in 2001, high nutrient concentrations have been recorded at several locations on Rathbun Creek and Summit Creek , while there was not measurable flow in Grout Creek until late 2003. From 2001 to 2004, the Big Bear Lake watershed experienced extremely dry years and therefore, nutrient inputs to the lake from the watershed were very low. Algae mats have been observed in a few locations in both Rathbun Creek and Summit Creek during the summer. Data for the three creeks are located in Appendix A.

This document summarizes the information used by the California Regional Water Quality Control Board, Santa Ana Region (Regional Board) to develop proposed TMDLs for nitrogen and phosphorus for Big Bear Lake. No TMDLs are proposed at this time for the three creeks – Rathbun, Summit and Grout Creeks. Studies are necessary to assess beneficial use impairment in the creeks. After such studies are completed, data will be reviewed and a determination will be made to either develop TMDLs or remove the three creeks from the Section 303(d) list for nutrients.

TMDLs are recommended for nitrogen and phosphorus loading to Big Bear Lake under dry weather conditions only. Insufficient data for wet or average hydrologic conditions are available to allow calibration of the lake water quality model used to calculate the TMDLs. The proposed TMDL implementation plan addresses this deficiency. A phased TMDL approach is proposed to allow for requisite study and refinement of the TMDLs, including consideration of wet and average hydrological conditions. It is proposed that compliance with the final numeric targets identified in the recommended TMDLs be achieved as soon as possible but no later than 2015.

The components of the Big Bear Lake nutrient TMDLs include:

1. Problem Statement. This section reviews the historic information used to include Big Bear Lake on the 303(d) list, and summarizes existing conditions using historic data and data collected since the listing. Monitored nutrient concentrations have at times exceeded a regional numerical total phosphorus and total inorganic nitrogen standard for Big Bear Lake (150 µg/L). Nutrient enrichment has contributed to excessive plant and algae growth.

2. Numeric Targets. The proposed numeric targets for Big Bear Lake for causal indicators (i.e., total phosphorus and total nitrogen) were derived using two different methodologies (Table 3-1). The recommended interim numeric target for total phosphorus was identified using the 25th percentile of recent monitoring data (2001-2002) from four main lake monitoring stations, while the final numeric targets for phosphorus and nitrogen were developed using an index system for lakes. The proposed numeric targets for response variables (i.e., macrophytes and chlorophyll *a*) were derived using three different methodologies (Table 3-1). The recommended interim numeric target for chlorophyll *a* was identified using the 25th percentile of recent monitoring data (2001) from four main lake monitoring stations for the growing season (May 1-October 31), while the final numeric target for chlorophyll *a* was developed using an index system for lakes. The final numeric targets for macrophytes are recommended based on literature values.

3. Source Analysis. This section quantitatively evaluates all the sources of total phosphorus and total nitrogen to Big Bear Lake. The sources are subdivided into external and internal loads, as well as nonpoint and point sources. External nonpoint sources are from forest and resort land uses and atmospheric deposition; external point sources are from high density urban and residential runoff subject to an NPDES permit; internal nonpoint sources are from nutrient fluxes from the sediment and nutrient loads from macrophytes. External land use sources were simulated using the Hydrological Simulation Program Fortran (HSPF); atmospheric loads were based on literature values; nutrient fluxes from sediment and nutrient loads from macrophytes were derived empirically from experiments conducted in 2002 and 2003. Total nutrient loads to Big Bear Lake from all sources are summarized in Table 4-7. As shown, average loads for dry conditions (1999-2003), average conditions (1990-2003) and wet conditions (1993) are calculated. The intent is to examine variations in nutrient loading associated with different hydrologic conditions. However, for the purposes of the proposed TMDLs, only dry weather loads were used, given limitations in data available to calibrate the lake water quality model (WASP) (see #4).

4. Linkage Analyis and TMDL (Load Capacity). The linkage analysis for Big Bear Lake discusses the relationship between external and internal nutrient loads and their effects on lake water quality and beneficial uses. The Water Quality Analysis Simulation Program (WASP) was used to determine the loading capacity (TMDL) for nutrients in Big Bear Lake under dry weather conditions. The dry weather loading capacities for total phosphorus and total nitrogen for Big Bear Lake are shown in Tables 5-2 and 5-3.

5. TMDL Allocations. Proposed wasteload allocations for the Big Bear Lake TMDLs are shown in Tables 6-1 and 6-2. These apply to urban runoff (from residential and high density urban land uses), which is the sole point source in the watershed and is regulated under an NPDES permit. Load allocations for total nutrients in the lake are proposed for source categories (forest, resort, atmospheric deposition, nutrient fluxes from sediment, and nutrient loads from macrophytes) in proportion to expected reductions from specific sources after the implementation of lake restoration activities (Tables 6-1 and 6-2). The proposed WLA and LAs are expressed as annual averages for dry hydrological conditions only.

6. Seasonal Variation and Critical Conditions. There are inherent seasonal (and annual) variations in nutrient dynamics in lakes and creeks, including the rates of nutrient input and internal cycling. WASP was calibrated with data collected from 2001-2003, reflecting this variation. Likewise, simulations with WASP take this variation into account. In addition, with the exception of chlorophyll *a,* the recommended numeric targets are expressed as annual averages. (The chlorophyll *a* numeric target is proposed as a growing season (May 1-October 31) average, since algae are not a problem at other times of the year.) By setting the numeric targets as annual means, emphasis is not placed on day-to-day or month-to-month variations in water quality. Instead year-to-year variations and improving trends in water quality are the focus of the TMDLs. Consideration of critical conditions ensures that even under the worst water quality conditions, water quality standards will be met with the loads established in the TMDLs. The critical condition for attainment of aquatic life and recreational uses in Big Bear Lake occurs during the summer and during dry years. The nutrient TMDLs for Big Bear Lake address critical conditions by focusing on the control of the internal sediment loads that dominate during these periods.

7. Margin of Safety. The TMDLs contain an implicit margin of safety, based on conservative approaches (e.g., the derivation of numeric targets based on the 25th percentile of data (2001-2002) for Big Bear Lake before the application of the aquatic herbicide Sonar; numeric targets are proposed as annual averages; and, the use of conservative assumptions in the WASP model setup, such as estimating a higher macrophyte density than what had been calculated previously).

8. Implementation Plan. This section describes the actions, regulatory tools and other measures necessary to achieve the TMDLs and wasteload and load allocations. Implementation of the proposed Big Bear Lake TMDLs is the responsibility of the United States Forest Service (USFS), Big Bear Mountain Resorts, the City of Big Bear Lake, the California Department of Transportation (Caltrans), the County of San Bernardino and the San Bernardino County Flood Control District (SBCFCD). Although not a responsible party, the Big Bear Municipal Water District has indicated its commitment to work as a cooperating entity to implement the nutrient TMDLs.

9. Monitoring Plan. In order to evaluate the effectiveness of actions and programs implemented pursuant to these TMDLs, the continuation of the existing watershed and lake water quality monitoring programs, with some minor modifications, as well as some additional monitoring elements, is recommended. Because the TMDLs are phased, follow-up monitoring and evaluation is essential to validate and revise the TMDLs as necessary.

1.0 INTRODUCTION

The proposed TMDLs for nutrients for Big Bear Lake are described in this document. Big Bear Lake was placed on the 303(d) list in 1994 for nutrients and noxious aquatic plants. Rathbun Creek, Summit Creek, and Grout Creek, which are tributary to the lake, were also placed on the 303(d) list in 1994 due to excessive levels of nutrients. However, at this time, TMDLs are not proposed for these creeks. Instead, because of uncertainties with respect to whether there is actual beneficial use impairment from nutrients in these creeks, staff recommends monitoring and a beneficial use assessment for these tributaries as identified in the implementation plan. The nutrients addressed in the TMDLs are nitrogen and phosphorus. The following paragraphs provide an introduction to the history of Big Bear Lake.

Big Bear Lake is a man-made reservoir created by the construction of Bear Valley Dam in 1883-84. The lake is located in the San Bernardino Mountains in San Bernardino County, approximately 100 miles northeast of Los Angeles and 40 miles northeast of the City of San Bernardino. It is the dominant feature of Big Bear Valley and its eastern area covers what was once a large flat meadow (Leidy 2003a, 6-11).

Frank E. Brown constructed the first dam in 1883-84 as a single arch dam across Bear Creek, a tributary of the Santa Ana River. During 1912, a 20-foot higher, multiple arch dam was completed downstream of the existing dam (Leidy 2003a, 12-16). These dams were constructed to store water for downstream irrigation uses in the Redlands/San Bernardino area.

In 1964, the Big Bear Municipal Water District (BBMWD) was created in an effort to develop programs and projects to stabilize the lake's water level. BBMWD is directed by a five-member elected Board of Directors. BBMWD's primary responsibility is the day-to-day management of Big Bear Lake, including the management of water releases, Bear Valley dam, recreation, and fisheries and wildlife. In January 1977, BBMWD acquired the title to the dam, the lake bottom, and the surface recreation rights of Big Bear Lake, for a purchase price of $4,700,000. Bear Valley Mutual Water Company (Mutual), which manages the distribution of lake water to downstream irrigation users, retained the water rights to Big Bear Lake (BBMWD 2002a). Mutual provides Big Bear Lake water as a source of domestic supply for users within its service area. BBMWD must provide Mutual with 65,000 acre-feet (af) of water in any rolling ten-year period. When Mutual needs water above this amount, BBMWD has several options. BBMWD can release water from the lake, or provide water from another source (i.e., groundwater or State Water Project)(BBMWD 2002a).

Big Bear Lake has a storage capacity of 73,320 acre-feet (af) and a water surface area of 2,971 acres at the elevation of the top of the dam (6743.2 feet). The lake is full at a gage height reading of 72.33 feet (Big Bear Watermaster 2001, 6). In order to maintain the recreational and wildlife uses of the lake, especially at the east end and other shallow areas, BBMWD implements a Lake Stabilization Program designed to stabilize Big Bear Lake within 15 feet of the dam elevation (i.e., in the range of 6728.2-6743.2 feet) over the long-term (BBMWD 2002a). Recreational uses of the lake are severely impacted if the lake level falls more than 15 feet (i.e., lake elevation of 6728.2 feet). Water levels have been measured continuously since July 1998 with the installation of a continuous lake level recorder by the BBMWD (Big Bear Watermaster 2001, 5). During most years, the lake level fluctuates no more than 3-5 feet, but during drought conditions, when no surface runoff from the surrounding watershed enters Big Bear Lake, the lake levels can fluctuate up to 15 feet. High evaporation levels, due to high wind and low humidity conditions, can remove up to 48 inches per year from the lake surface. This number varies seasonally, depending on temperature, lake level (and thus surface area), and other factors. Evaporation is calculated monthly, using precipitation, temperature and other data and is reported in BBMWD's annual Watermaster reports. Lake inflow is calculated monthly by the following formula: Inflow = Evaporation + Releases + Spills + Leakage + Net Withdrawals - Change in Storage. Inflow is calculated rather than measured (BBMWD, 2002a). Average annual inflow to Big Bear Lake approximates 17,300 af and adjusted evaporation approximates 11,300 af based on Watermaster data from 1977-2001 (Table 1-1).

The State Water Resources Control Board adopted Order WR No. 95-4 to assure adequate flows downstream of the dam to protect fisheries in Bear Creek. Order WR No. 95-4 requires minimum outflows of 0.3 cfs at Station B (300 feet below Bear Valley Dam) and 1.2 cfs at Station A (West Cub Creek confluence with Bear Creek) (BBMWD 2002a). Big Bear Lake is also utilized as a source of water for snow making operations. Snow Summit and Bear Mountain ski resorts can acquire a total of 1000 af of lake water per year (BBMWD 2002a).

Table 1-1. Big Bear Lake statistics

Lake Elevation	6743.2 feet
Lake length	7 miles
Average lake width	½ mile
Shoreline	22 miles
Max depth at dam	72.33 feet
Max lake capacity	73,320 acre-feet
Big Bear Valley Length	12.5 miles
Average inflow	17,300 af/year
Average outflow at dam[1]	5,510 af/year
Average evaporation rate[2]	11,300 af/year
Average lake capacity	58,500 af/year
Average detention time of water (avg lake capacity/avg outflow at dam)	11 years

Source: BBMWD 2002a; BBMWD 2002b
[1]Outflow includes dam releases, spills, leakage and withdrawals
[2]Evaporation is calculated with the Blaney Criddle formula using the estimated evaporation rate and the average surface area of the lake during the month (Big Bear Watermaster 2001, 6).

1.1 Big Bear Lake Watershed

The Big Bear Lake watershed is approximately 37 square miles and is drained by more than 10 streams (Figure 1-1). Local stream runoff and precipitation on the lake are the water supply inputs to Big Bear Lake. Big Bear Lake drains to Bear Creek, which is tributary to the Santa Ana River. Twelve percent of Big Bear Lake's drainage basin consists of the lake itself.

The mountain peaks surrounding the Big Bear Basin rise to approximately 7,800-8,600 feet along the southern rim of the lake. Some prominent peaks include Butler Peak (8,537 feet) to the west, Bertha Peak (8,198 feet) to the north, and Snow Summit (8,470 feet) to the south. The watershed is dominated by yellow pine and white fir; junipers and pinyon pine are found on the drier slopes. The lower reaches of most of the Big Bear Lake tributaries, particularly those in the eastern area, are underlain with older and younger alluvium. The western portion and the upper eastern portions of the lake are dominated by undifferentiated basement complex rocks, which are mostly impervious.

The underlying groundwater basin is used for domestic water supply of the Big Bear Valley and is mined in three ways: wells drilled into alluvial deposits, bedrock slant wells, and springs. During the 1970s, the Big Bear Lake watershed was divided into seven hydrographic subareas which were “based essentially on drainage boundaries, to facilitate the description of the region and for the tabulation of pertinent data according to a geographic locale”(Neste, Brudin, and Stone, Inc. 1973, 3-12). These hydrographic subareas are termed Village, Rathbone, Division, North Shore, Grout Creek, Mill Creek, and Gray’s Landing (Neste, Brudin, and Stone, Inc. 1973, 3-14) (Figure 1-2). The City of Big Bear Lake Department of Water and Power (DWP), established in 1989, obtains its water from local groundwater and provides domestic water service to the city and areas outside the city limits. The Division, Village and Rathbone (Rathbun) subareas provide the groundwater used by the city (City of Big Bear Lake 1999, ER-31).

(A) Rathbun (Rathbone) Creek Subwatershed. The Rathbun Creek subwatershed is located in the Moonridge area south of Big Bear Lake. The subwatershed drains approximately 4090 acres of land (6.4 square miles), 30% within the City of Big Bear Lake and the remainder within the San Bernardino National Forest (Figure 1-3). There are four major drainages included in the Rathbun Creek subwatershed: Rathbun Creek, Deer Canyon, Sand Canyon, and Bow Canyon. Rathbun Creek is 3.5 miles long. The Rathbun Creek subwatershed is characterized by steep fluvial/V-shaped erosional and mildly sloping alluvial valley bottom types with elevations from 6700 to 8900 feet above sea level (USDA 1995, 1). Bear Mountain ski area is located in the upper reaches of Rathbun Creek, Deer Canyon and several unnamed drainages, while Snow Summit ski area is located within the headwaters of Summit Creek, which drains into the Rathbun Creek watershed. Most of the drainage area has been substantially altered by human activities. The paragraphs below describe the condition of Rathbun Creek from the confluence of Sand Canyon Channel to the mouth.

Sand Canyon Channel
Sand Canyon Channel merges with Rathbun Creek at Moonridge Road. This channel is an ephemeral stream dominated by snowmelt runoff. Soils in the area are coarse textured. The channel gradient is approximately 6 percent and is devoid of riparian vegetation. The channel is partially maintained by the San Bernardino County Flood Control District (SBCFCD) (USDA 1995, 3).

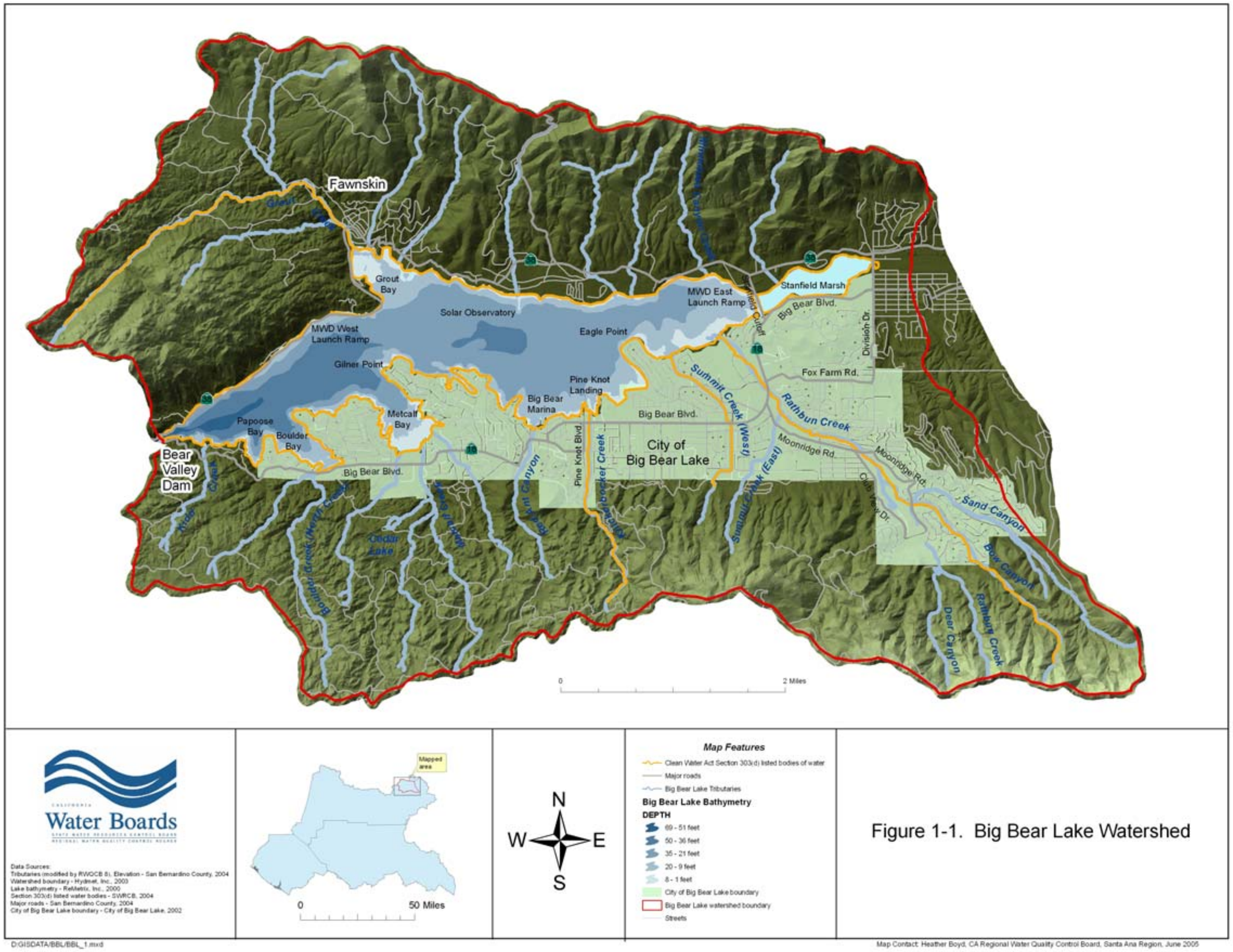

Figure 1-1. Big Bear Lake Watershed

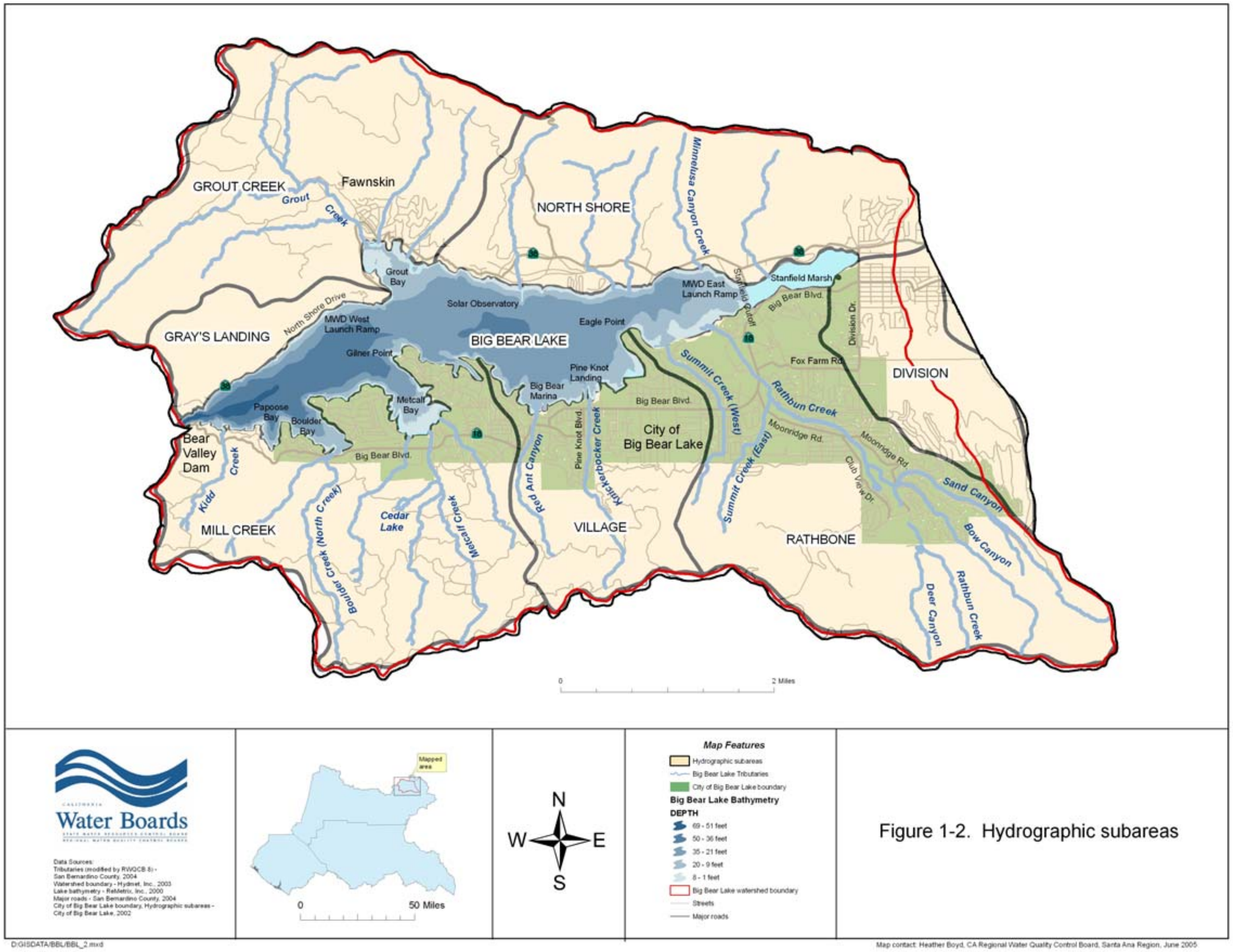

Figure 1-2. Hydrographic subareas

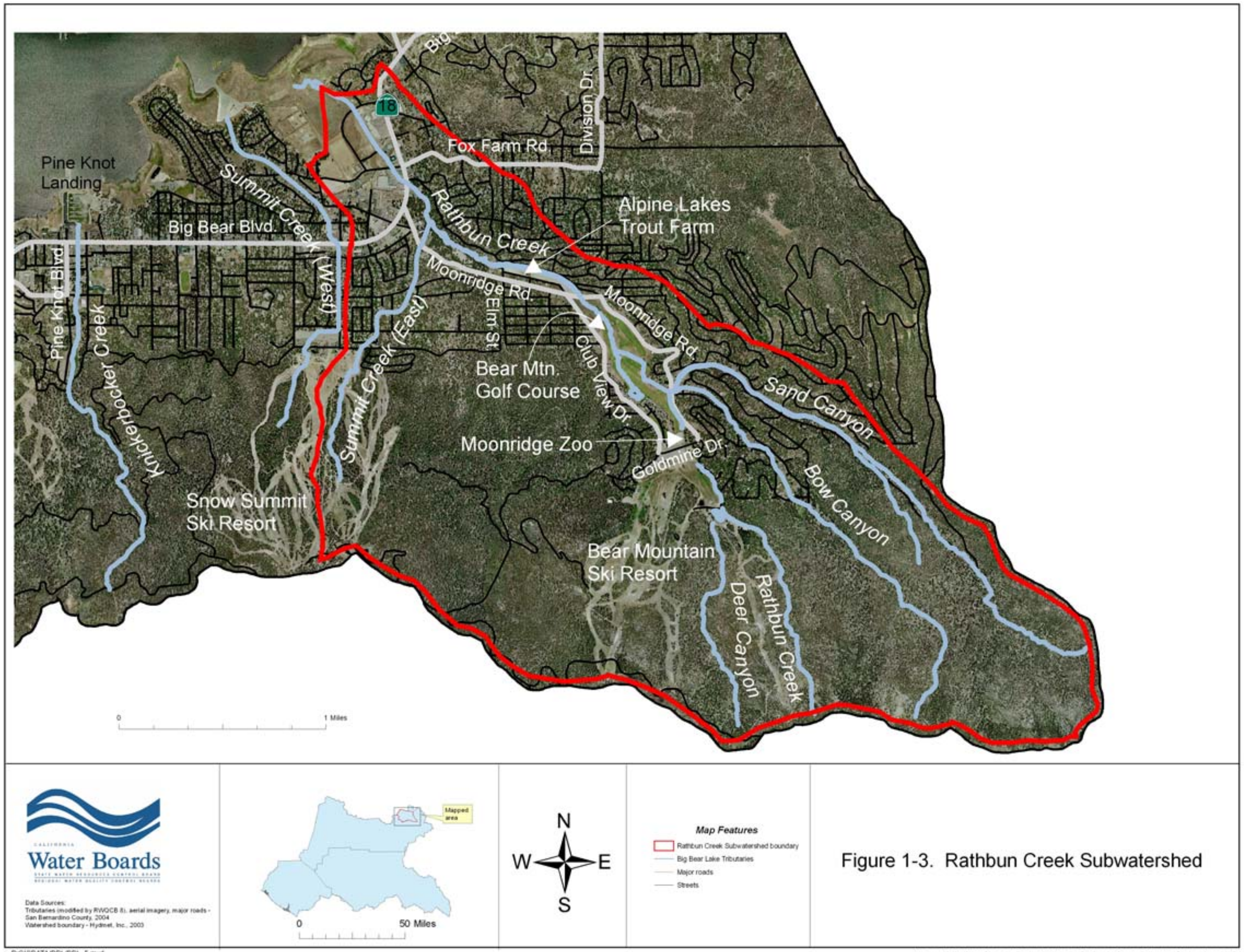

Figure 1-3. Rathbun Creek Subwatershed

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Map contact: Heather Boyd, CA Regional Water Quality Control Board, Santa Ana Region, June 2005

Sand Canyon Channel has been widened to 40 feet, with 2:1 side slopes for flood protection for the nearby homes. The channel is unlined alluvial sediment consisting of fine to coarse-grained sands and gravels with interbedded silt (Black and Veatch 1990, 7). This channel is experiencing streambed erosion and bank sloughing (USDA 1995, 3). Modifications to Sand Canyon Channel, consisting of armoring the banks about 600 feet upstream of Moonridge Road, were completed in 1997 with funds from a Clean Water Act Section 319 (h) grant. In addition, supported by a Clean Water Act Section 319(h) grant awarded in 1999, the culvert at Teton Drive was replaced and the banks along the north and south sides of Teton Drive were armored. This project, located upstream of the first 319(h) project, was completed in 2002.

Rathbun Creek: Goldmine Road to Moonridge Road (Golf Course)
Historically, Rathbun Creek meandered, with flows from Sand and Bow Canyons joining the creek near the center of the valley. The upper portion of the creek was rerouted along the east side of the valley to allow for the golf course. This adjustment straightened the creek and in the process caused the creek to become entrenched (USDA 1995, 5). The 43-acre golf course was formerly a meadow (City of Big Bear Lake 1999, OPR-3). The Moonridge Zoo (2.7 acres) is located at the intersection of Moonridge and Goldmine Roads (City of Big Bear Lake 1999, OPR-3). Flow from the watershed area above Lassen Drive is directed into a culvert that outlets immediately below and to the west of the zoo. The lower portion of the creek, below the golf course to Moonridge Road, is a naturally meandering channel with a floodplain width between 30-50 feet. Horse grazing occurs below the golf course. Grazing has impaired the growth of riparian vegetation and contributes animal waste, high in nitrogen, which is discharged into the creek through surface runoff and leaching (USDA 1995, 5).

Rathbun Creek – Moonridge Road to the Trout Pond
A commercial trout pond (1 acre in size) is located within Rathbun Creek (City of Big Bear Lake 1999, OPR-3). Concrete check dams between Moonridge Road and Elm Road that serve as sediment traps are also effective as grade control structures. Below Elm Road there is a diversion that serves to divert moderate flows around the trout pond, while allowing low and high flows to continue flowing in the natural channel. Between Moonridge Road and the diversion downstream of Elm Road, the creek is straightened and channelized and consists of coarse loamy soils with an average channel slope of 2 percent (USDA 1995, 6-7).

Rathbun Creek – Trout Pond to State Highway 18
From the trout pond to Big Bear Boulevard (State Highway 18), the entire reach of Rathbun Creek is vegetated with tall shrub willows. After the installation of a 9x12 foot double box culvert under State Highway 18, a headcut developed in the upper section of this reach. Summit Creek drains the eastern edge of the Snow Summit Ski area. Runoff enters a trapezoidal concrete channel and flows through the residential area between the ski area and Moonridge Road. The creek (shown in Figure 1-3 as Summit Creek East) joins Rathbun Creek behind the Big Bear Inn through a 5x8 foot box culvert (USDA 1995, 8). A bank stabilization project was completed below the box culvert near the confluence of Summit and Rathbun Creeks in 1999. The banks were stabilized with rock and filter fabric (BBMWD 2002a).

Rathbun Creek – State Highway 18 to Big Bear Lake
From State Highway 18 to Big Bear Lake, Rathbun Creek was historically a natural, meandering stream channel. The SBCFCD straightened and channelized the creek into an earth graded channel. Because of this channelization, sediment is not deposited throughout the floodplain but remains in creek flow and is deposited into the lake (USDA 1995, 9).

<u>*Bear Mountain Parking Areas*</u>
Two gravel overflow parking lots operated by Bear Mountain ski resort border Rathbun Creek. One parking lot covers approximately 20 acres and is bordered by Moonridge Road, Elm Road, and Rathbun Creek. The second parking lot is located upstream of the Trout Pond between Rathbun Creek and the diversion channel. This parking lot is approximately 5 acres in size. Plowed snow enters the creek. In addition, rain, ice melt, and snowmelt transport untreated sediment and pollutants into Rathbun Creek (USDA 1995, 16).

(B) Summit Creek Subwatershed. Summit Creek has a drainage area of approximately 0.55 square miles (Figure 1-4). All of the creeks that drain from Snow Summit are referred to as Summit Creek. The upper portion of the Snow Summit ski resort drains into the Rathbun Creek subwatershed. Summit Creek (also referred to as West Summit Creek) travels under Summit Boulevard until it reaches Park Avenue. Bear Valley Paving is located right below Park Avenue at Garstin Drive. The creek flows to the west of Bear Valley Paving and has been riprapped in places along both banks and realigned approximately 40-80 feet to the south of its previous location. At the junction of Swan Drive and Marina Point, a box culvert exists. The creek runs through the industrial section of the City of Big Bear Lake below State Highway 18.

(C) Grout Creek Subwatershed. The major town within the Grout Creek drainage basin (Figure 1-5) is Fawnskin, which is within the County's unincorporated areas. Other areas within this drainage basin are in the U.S. Forest Service (USFS) area. Grout Creek has a drainage area of approximately 4.5 square miles. Grout Creek is the longest tributary within the Big Bear Lake drainage basin at 3.8 miles long (Siegfried, Herrgesell, and Loudermilk 1979, 2), with a gradient of approximately 400 feet per mile (Neste, Brudin, and Stone, Inc. 1973, 2-3).

Climate. Precipitation varies greatly in the Big Bear area due to a rainshadow effect. The west end of the lake, near the dam, typically receives an average of 30-35 inches per year while at the east end of the lake, the average is less than 20 inches (Figure 1-6). The Big Bear Lake Dam weather station, established in 1883, has been monitoring precipitation continuously starting with the first precipitation records from the 1883-84 season. Information on other daily and hourly precipitation records in the San Bernardino Mountains is found in the modeling report (BBMWD, Hydmet, Inc. and AquAeTer, Inc. 2003).

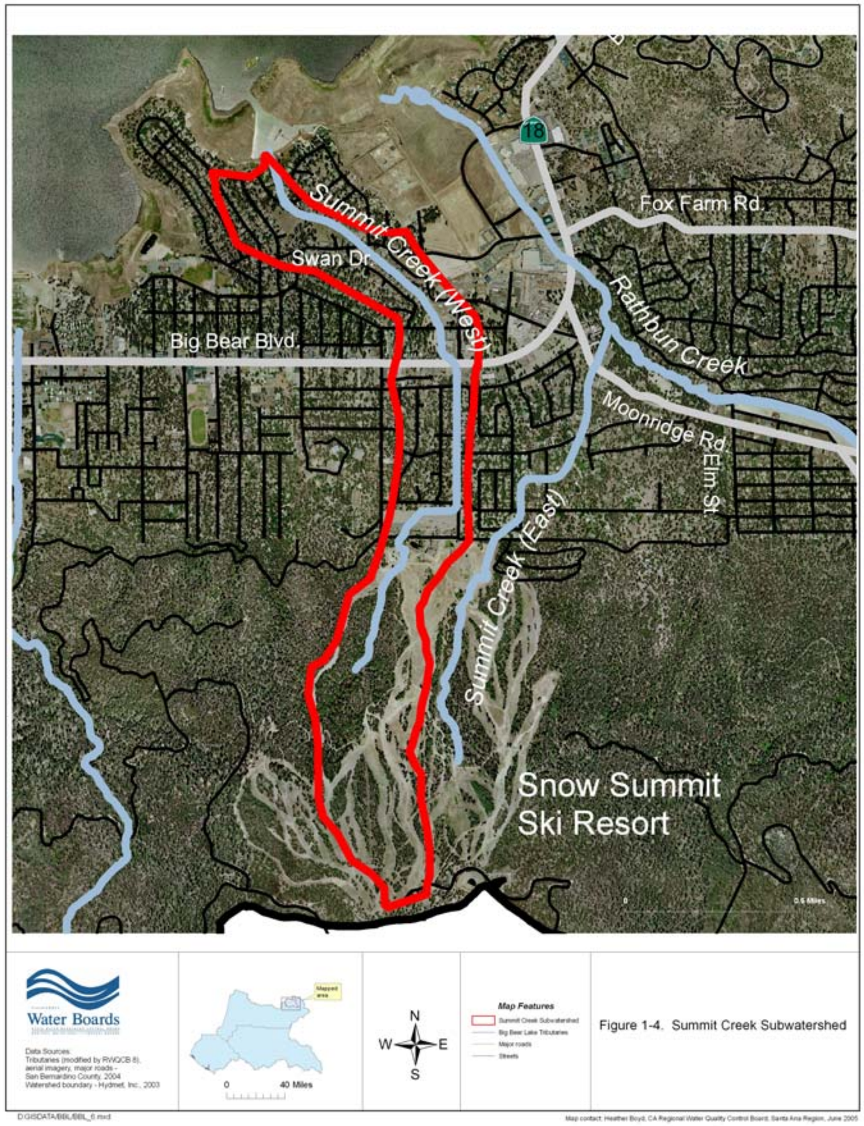

Figure 1-4. Summit Creek Subwatershed

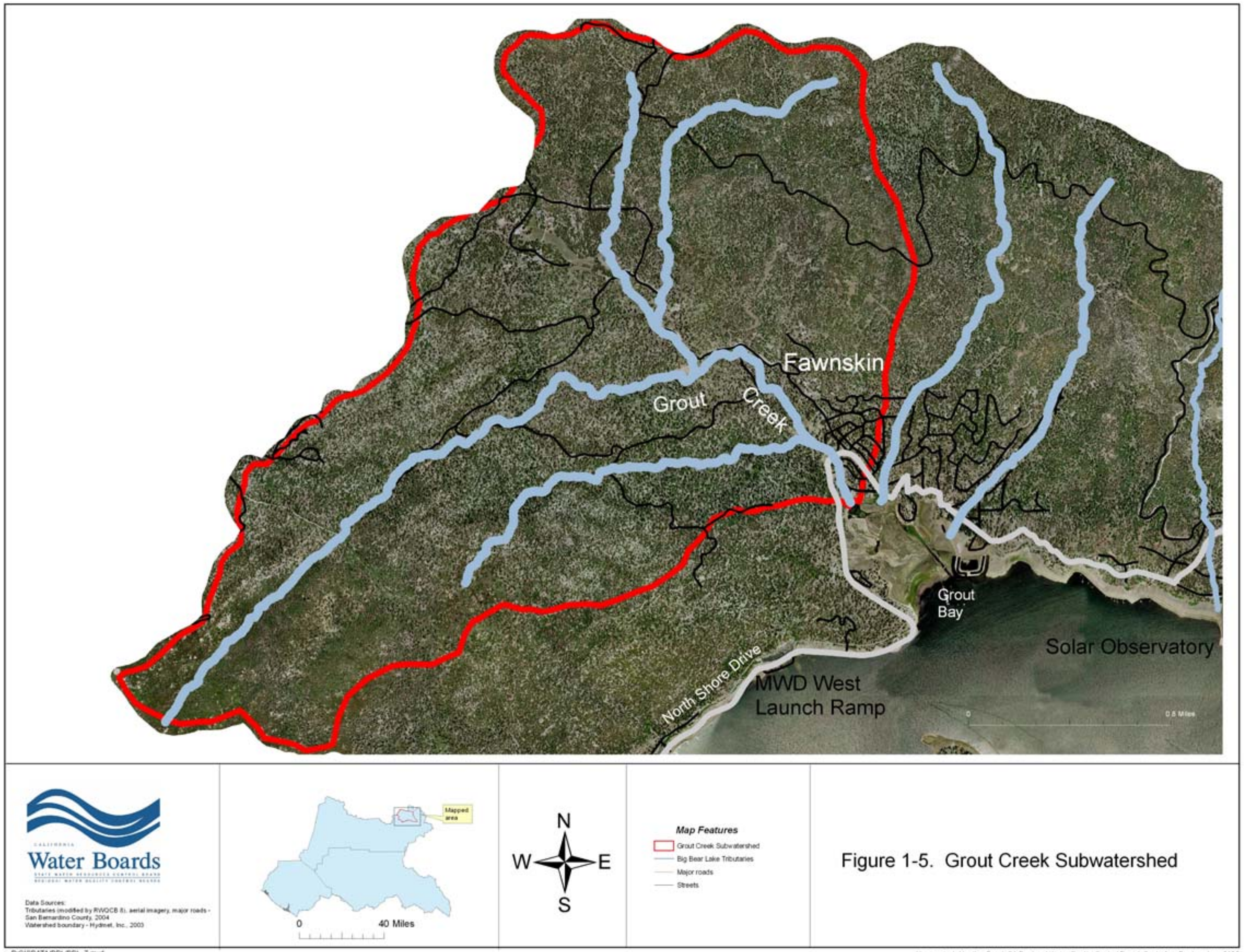

Figure 1-5. Grout Creek Subwatershed

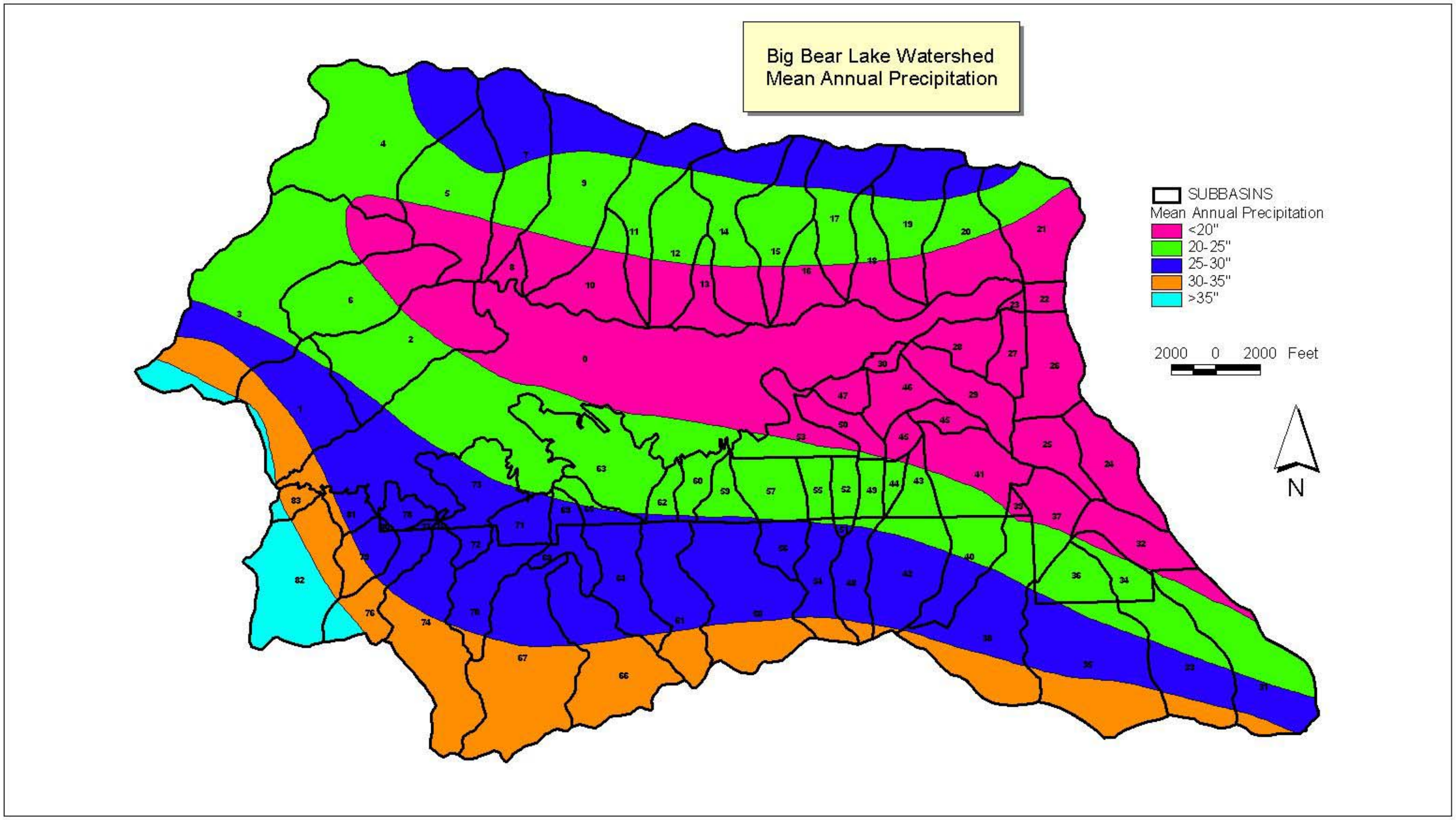

Figure 1-6: Mean annual precipitation for the Big Bear Lake watershed (source: BBMWD, Hydmet, Inc., and AquAeTer, Inc. 2003)

Figure 1-7 shows annual precipitation amounts, in inches per calendar year, measured at Bear Valley Dam. These annual numbers do not include snowfall, which does occur at this elevation. Most precipitation occurs from December through March, as indicated by monthly precipitation averages. Over a period of 56 years, the wettest year observed was in 1969 (Figure 1-7). Since the inception of the TMDL Task Force's[1] monitoring program (2001), recorded precipitation levels have been low. Consequently, lake levels, which are dependent upon surface runoff and direct precipitation, have also been extremely low (Figure 1-8).

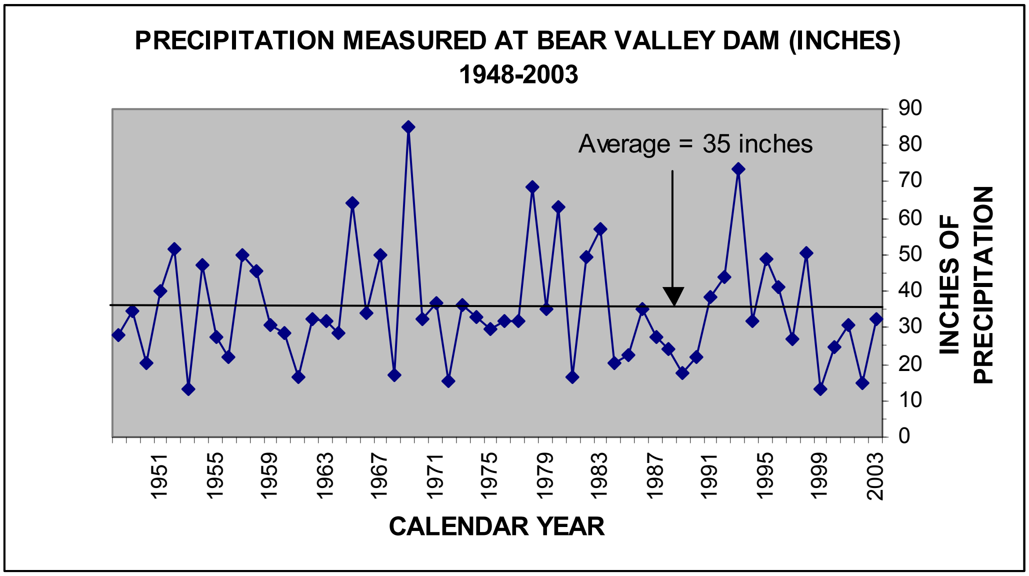

Figure 1-7. Annual precipitation, in inches, measured at Bear Valley Dam (Source: BBMWD 2004b)

[1] The TMDL Task Force was created by the Big Bear Municipal Water District in 2000. It consists of a number of local agencies and private interest groups including: the City of Big Bear Lake; San Bernardino County Flood Control District (SBCFCD); Big Bear Area Regional Wastewater Agency (BBARWA); and Regional Board staff; Caltrans; Big Bear Mountain Resorts; the USFS; and others. BBMWD, acting on behalf of the Big Bear TMDL Task Force, has hired Tim Moore of Risk Sciences, Inc., as a consultant to develop and execute the appropriate studies to support TMDL development and to secure funding sources for the needed studies. The Task Force budget was created by a partnership of the BBMWD, the City of Big Bear Lake, SBCFCD, and BBARWA.

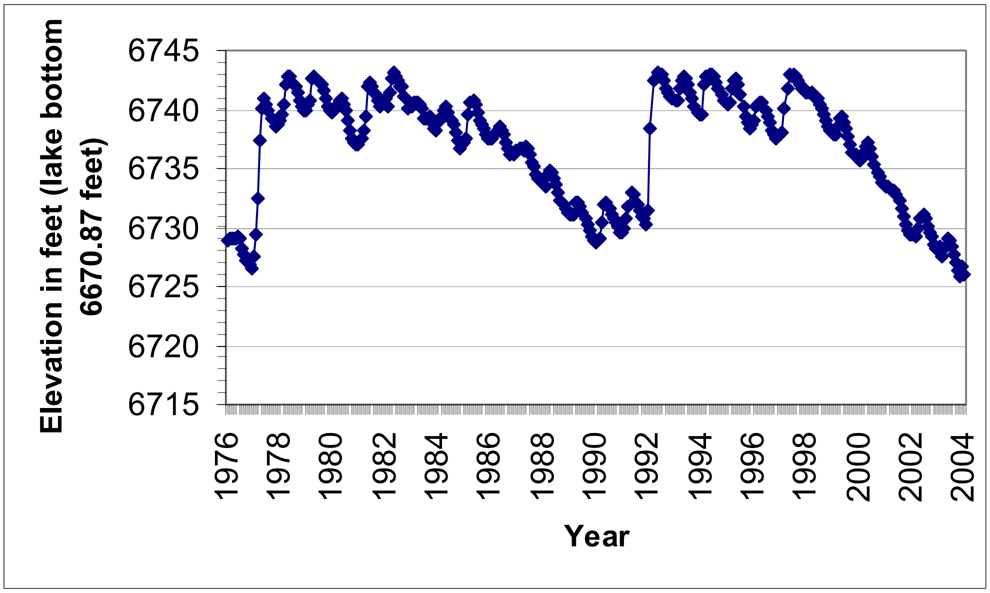

Figure 1-8: Lake elevation (in feet) for the period of record 1977- 2004 (full pool at 6743.2 feet) (Source: BBMWD 2004a)

Wastewater. Big Bear Area Regional Wastewater Agency (BBARWA), a joint powers authority created in 1974, provides interceptor service, secondary treatment and disposal by reclamation of all collected municipal wastewater in the Big Bear Valley (Engineering Resources of Southern California 1998, 1). The agency is located in Big Bear City and all the treated wastewater is disposed of in Lucerne Valley (Engineering Resources of Southern California 1998, 2). The sewerage system was installed in response to a prohibition on the use of subsurface disposal systems adopted by the Regional Board in 1973; there are limited exemptions to the prohibition, largely applicable to developments on large parcels outside existing sewer service area boundaries.

Land Use. The USFS is the largest landowner in the Big Bear area. The two ski resorts, Bear Mountain and Snow Summit, operate under special use permits from the USFS. Bear Mountain ski resort has 748 total permit acres; of that total, 198 acres are developed with 34 trails. The remaining acreage (550 acres) is undeveloped land that includes Deer, Goldmine and Bow Canyons (Bear Mountain Resort 2003). Snow Summit ski resort, built in 1952, is 620 acres in size, with 230 skiable acres (City of Big Bear Lake 1999, ER-24, OPR-6). Snow Summit is also used for mountain biking during the summer. A third abandoned ski resort, Snow Forest, is located to the southwest of Knickerbocker Creek. The San Bernardino Recreation Club and the Big Bear Lake Park District opened this area to skiing and tobogganing in 1939 (City of Big Bear Lake 1999, ER-24). This site is a contributor of sediment and potentially nutrients to Big Bear Lake.

The only incorporated city in the Big Bear Lake watershed is the City of Big Bear Lake, which was incorporated in 1980. The permanent population of the City of Big Bear Lake in 1980 was 4,923 and 6,049 in 1998. Of a total of 9,019 dwelling units in the City as of January 1, 1998, only 26% were permanently occupied. An estimated 50,000 or more people visit the City of Big

Bear Lake on a peak holiday weekend and the U.S. Forest Service estimates 5 million people visit Big Bear Valley each year (City of Big Bear Lake 1999, LU-4, LU-6).
A total of 4,466 acres are currently in the City of Big Bear Lake planning area and are designated for a variety of land uses, including residential, commercial, and industrial. The southern boundary of the City of Big Bear Lake's sphere of influence follows the USFS' boundary (City of Big Bear Lake 1999, LU-3) (see Figure 1-1).

For modeling purposes, the Big Bear Lake watershed was delineated using the watershed boundaries from CalWater v. 2.2 and incorporated the Hydrologic Subarea Boundary (HSA) of Bear Valley (801.71). Further refinement of the watershed boundary was obtained using the USGS 7.5 Minute Quadrangle sheets (Fawnskin, Moonridge, Big Bear Lake, and Big Bear City). The watershed was then further divided into 83 subbasins (Figure 1-9) to permit the greatest flexibility in simulating watershed processes. The subbasins were delineated based on topographic features, stream reaches, and the storm water system Geographical Information System (GIS) files supplied by the City of Big Bear Lake. The Rathbun Creek, Grout Creek, and Summit Creek subwatersheds consist of subbasins 31-46; 3-6; and 48-50, respectively, as shown in Figure 1-9.

Utilizing GIS analysis, the areas of various types of land use within the watershed were determined (Table 1-2 and Figure 1-10). These land uses were also used for the Hydrological Simulation Program Fortran (HSPF) model development (see Section 4.0). Land use layers consisted of 1996 aerial photos from the USGS and the City of Big Bear Lake's current (2002) zoning map. The following ratios were used to determine the percentage of impervious/pervious area for each land use: forest north (0.5%/99.5%); forest south (0.5%/99.5%); resort (5%/95%); residential (15%/85%); and high density urban (50%/50%)[2]. The majority of the land use area in the Big Bear Lake watershed is still pervious. The predominant land use in the watershed is forest (62.7%). The resort land use designation includes the ski resorts, parks and golf courses. The historic ski resort, Snow Forest, near Knickerbocker Creek, was also included in the resort land use category. High density urban includes commercial, industrial and multiple family land uses (BBMWD, Hydmet, Inc., and AquAeTer, Inc. 2003).

[2] The nomenclature "Forest North" and "Forest South" refer to the topographic aspect, not to whether the forest is located to the north or south of the lake. Distinctions in topographic aspects were important to the HSPF modeling effort because of the effect of snow accumulation and snowmelt on water resources. North facing slopes accumulate more snow and melt slower than do south facing slopes.

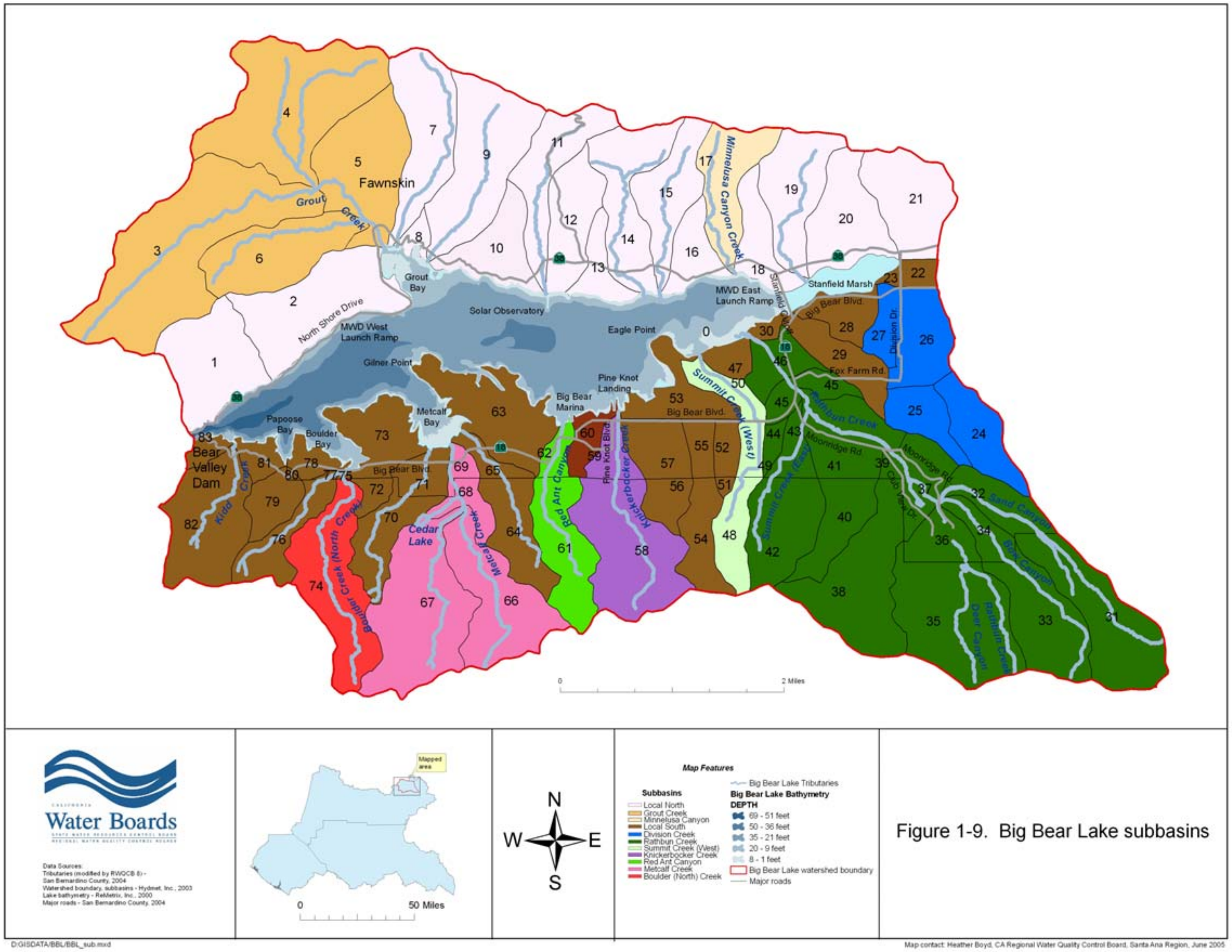

Figure 1-9. Big Bear Lake subbasins

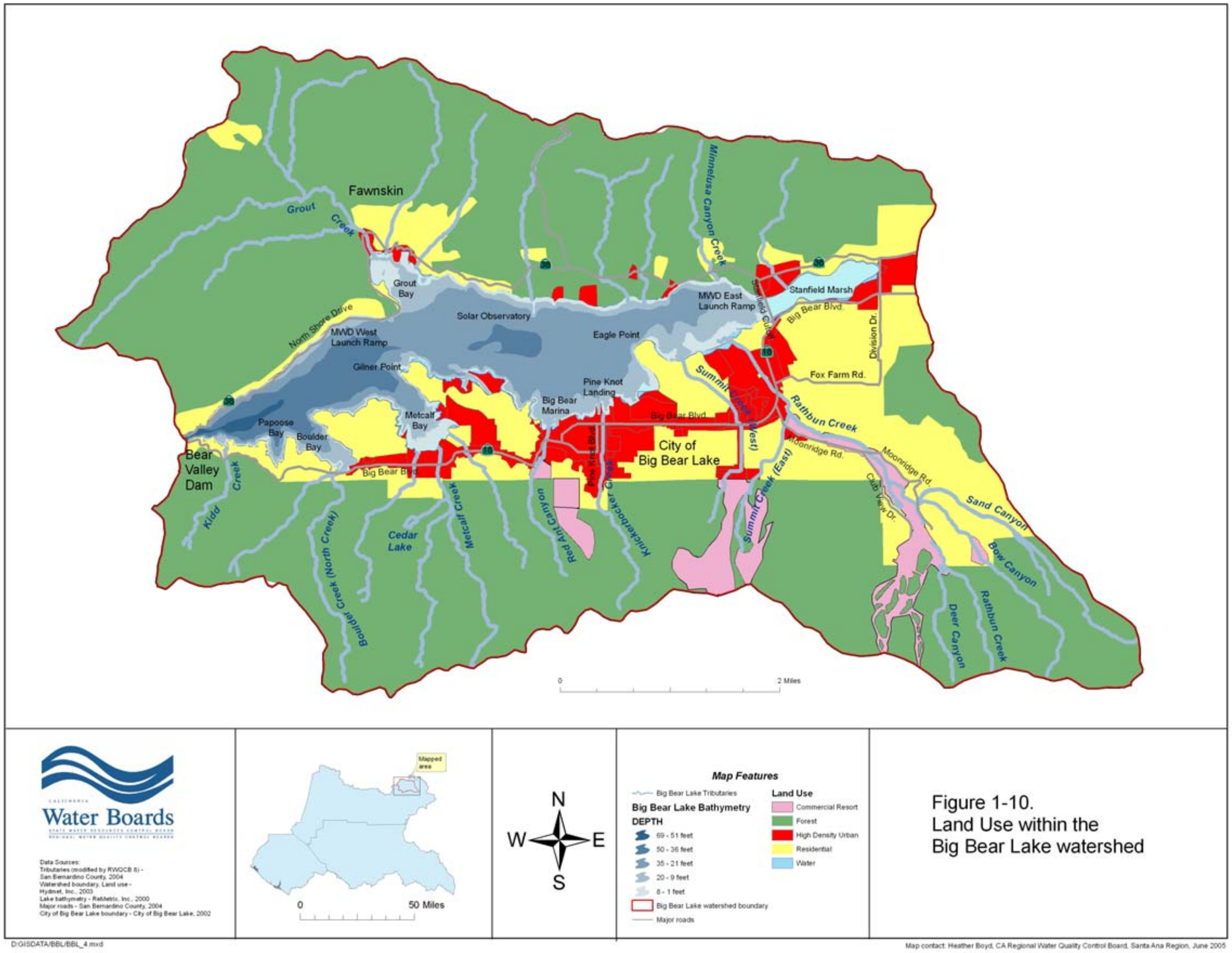

Figure 1-10.
Land Use within the
Big Bear Lake watershed

Table 1-2. Impervious and Pervious land use distribution in the Big Bear Lake watershed

	AREA (acres)			
Major Land Use Type	**Impervious**	**Pervious**	**Total**	**Percentage of Watershed (%)**
Forest North	38	7595	7,633	32.9
Forest South	35	6876	6,911	29.8
Resort	35	669	704	3.0
Residential	580	3287	3,867	16.7
High Density Urban	644	644	1,288	5.5
Big Bear Lake	-	-	2,808	12.1
Total Watershed	1,332	19,071	23,211	100

Note: Forest North and Forest South refer to the aspect, not to whether the forest is located to the north or south of the lake.
Source: Modified from Hydmet, Inc. 2004

Shown in Table 1-3, are the pervious and impervious land use distributions for Rathbun Creek, Summit Creek, and Grout Creek. The percentages of impervious/pervious land use identified for the watershed as a whole were also used for these subwatersheds. The predominant land use in all three of the subwatersheds is forest; Grout Creek subwatershed is >96% forest. Both the Rathbun Creek and Summit Creek subwatersheds include ski resorts as one land use category. The most urbanized of these three subwatersheds is Summit Creek.

Table 1-3. Impervious and pervious land use distribution in the Rathbun Creek, Summit Creek, and Grout Creek subwatersheds

Major Land Use Type	AREA (acres) Impervious	Pervious	Total	Percentage of Subwatershed (%)
Rathbun Creek				
Forest North	10	1991	2001	49
Forest South	2	434	436	11
Resort	9	417	426	10
Residential	151	856	1007	25
High Density Urban	110	110	220	5
Total subwatershed	282	3808	4090	100
Summit Creek				
Forest North	0	56	56	16
Forest South	0	9	9	3
Resort	5	101	106	30
Residential	17	95	112	32
High Density Urban	33.5	33.5	67	19
Total subwatershed	55.5	294.5	350	100
Grout Creek				
Forest North	6	1205	1211	42
Forest South	8	1565	1573	54
Resort	0	0	0	0
Residential	16	88	104	3.6
High Density Urban	7.5	7.5	15	0.5
Total subwatershed	37.5	2865.5	2903	100.1

Note: Forest North and Forest South refer to the aspect, not to whether the area is located to the north or south of the lake
Source: Modified from Hydmet, Inc. 2004

Fish and Wildlife. There are two fisheries in Big Bear Lake, a warm water fishery consisting of centrarchids (largemouth bass, bluegill and pumpkinseed) and channel catfish, and a cold water fishery with frequent stocking of rainbow trout. In addition, there are large populations of carp present in the lake. The three centrarchids, members of the Sunfish family (Family taxon Centrarchidae), spawn at different water temperatures. The largemouth bass spawns in the early spring when water temperatures are at 14-16º C, the bluegill spawns when water temperatures are at about 18-21º C, and the pumpkinseed spawns when water temperatures are at about 20º C. These fish have different dietary and habitat preferences as well. The pumpkinseed prefer damselfly naiads and gastropods and prefer the dense macrophyte beds. The bluegill's diet consists of zooplankton, damselfly naiads, and chironomids and they prefer the fringe of the weed beds. The largemouth bass' diet consists of chironomids, crayfish and fish.

The bass also prefer the fringe of the weed beds but select larger prey than the bluegill (Siegfried et al. 1978, 49-50). Half-pound Rainbow trout from the Mojave Fish Hatchery are stocked in Big Bear Lake twice a month from April to November, with a 36,000 lb allotment per calendar year. One-hundred fifty thousand subcatchables are also stocked per year. These smaller, 6-inch rainbow trout are an Eagle Lake trout strain (Uplinger 2000). According to the Big Bear Municipal Water District (2002a), there are 9 species of fish in the lake (Largemouth bass, smallmouth bass, silver salmon, bluegill, pumpkinseed, crappie, catfish, carp and rainbow trout). Because of these habitat and dietary differences, it is important that the aquatic plant community in the lake consist of a variety of species and that no one species forms a monoculture, as Eurasian watermilfoil has essentially done in Big Bear Lake (Section 2.0). A diverse aquatic plant community is necessary to support the diversity of fish and other wildlife species. The development of monocultures threatens the diversity of the biota.

Rare/Threatened/Endangered Species. Bald eagles winter at Big Bear Lake and adjacent Baldwin Lake. In 1998, there were approximately 15 to 28 bald eagles. The eagles perch in trees within wooded areas along the southern lakeshore, around Metcalf Bay and Eagle Point, and along the eastern shore of the lake. They also forage on fish within Big Bear Lake. Any outdoor activity that could disturb the eagles should be restricted from December 1 through April 1 (City of Big Bear Lake 1999, ER-5, ER-6).

2.0 PROBLEM STATEMENT

Eutrophication is a natural progression of nutrient enrichment and basin filling that lakes and reservoirs experience. Without human-induced or "cultural" eutrophication, lakes naturally take thousands of years to progress from an oligotrophic condition, in which the water is clear, but nutrient-poor, to an eutrophic condition, in which the water is less clear, but nutrient-rich. Eutrophy is characterized by excessive nutrients, proliferation of plant growth (phytoplankton[3], periphyton[4] and macrophytes[5]), an anaerobic hypolimnion[6] during the summer, poor transparency and domination of bottom-dwelling fish (e.g., carp).

Historical studies and data have indicated that Big Bear Lake is eutrophic (Pearson and Irwin 1972, 1, 17; Irwin and Lemons 1974, 1, 36-39; Siegfried et al. 1978, 55-60; Siegfried and Herrgesell 1979a, 1-2, 24-28; Courtier and Smythe 1994). The researchers noted that both internal recycling of nutrients from sediments and nonpoint source loading to the lake must be reduced to improve Big Bear Lake's trophic state. Leidy's (2003a) report offers an alternative hypothesis on the origin of eutrophic conditions in Big Bear Lake. The report contends that the lake was always eutrophic and that the conditions presently seen are not due to anthropogenic activities, but simply represent surplus nutrient loadings due to the fact that the area in which the Bear Valley Reservoir, and subsequently Big Bear Lake were sited was already nutrient-enriched (36).

Nitrogen and phosphorus are essential to the growth of plants and animals. However, in large amounts these nutrients can result in stimulation of excessive growth of macrophytes and algae, resulting in physical, chemical and biological changes that in turn affect the nature and abundance of the animal community. The following paragraphs discuss macrophytes, algae and the nitrogen and phosphorus cycles.

Macrophytes. Macrophytes are any macroscopic form of aquatic plant life and include Eurasian watermilfoil and coontail (Wetzel 2001, 528). Aquatic macrophytes can be either attached to the substrate (e.g., Eurasian watermilfoil) or not rooted and freely floating (e.g., coontail). Attached forms include emergent macrophytes[7], floating-leaved macrophytes[8] and submersed macrophytes[9]. Most freely floating macrophytes are confined to protected areas such as bays, where they absorb nutrients through the water column and are usually an indication of nutrient rich waters (Wetzel 2001, 531). Most submersed macrophytes are usually found in water depths greater than 1 meter because wave exposure is lessened and sediment stability is increased (Wetzel 2001, 541).

Macrophytes are an important part of the aquatic ecosystem, providing cover, nursery and foraging habitat for fish and other wildlife. Macrophytes also provide erosion control by protecting and stabilizing the shoreline. Macrophyte growth is controlled by a variety of factors, including temperature, light, and sediment type. The rooted macrophytes are restricted to the

---

[3] Phytoplankton are floating, microscopic algae.
[4] Periphyton are organisms that grow on underwater surfaces.
[5] Macrophytes are any macroscopic form of aquatic plant life (Wetzel 2000, 528).
[6] The hypolimnion is the bottom layer of a thermally stratified lake and is characterized by cold and unmixed waters.
[7] Emergent macrophytes occur in soils where the water table is approximately 0.5 m below the soil surface up to water depths of 1.5 m (include bulrushes (*Scirpus)* and cattails (*Typha*)) (Wetzel 2001, 529)
[8] Floating-leaved macrophytes occur attached to sediments at water depths from 0.5 m to 3 m and include water lilies and pondweed (*Potamogeton)* (Wetzel 2001, 529)
[9] Submersed macrophytes occur at all depths within the photic zone (includes Eurasian watermilfoil)

littoral zone[10] due to limits on light penetration. Rooted macrophytes obtain the majority of their nutrients from the sediment, while epiphytic algae[11] attached to the macrophytes uptake nutrients from the water column. The rooted macrophytes "pump" nutrients from the sediments into their tissues. During macrophyte growth and decomposition, nutrients can be released from the plant tissues into the water column, but most of the nutrients released by the macrophytes is sequestered by the attached algae and recycled (Wetzel 2001, 549).

Algae. Algae, like macrophytes, need light and nutrients to grow. If turbidity is high, if there are macrophytes present, or if there is already an abundance of algae present in the lake, then algae growth will be limited by light. If the nutrient necessary for algae growth is controlled, or if grazers (zooplankton[12]) are abundant, then algae growth will also become limited. Algae can be filamentous, colonial, or unicellular and are classified according to pigment composition, among other physiological characteristics (Wetzel 2001, 332-337). Blue-green algae usually are a nuisance because they form massive blooms, which lead to taste and odor problems, as well as possible toxicity. Blue-green algae also carry out nitrogen fixation (transformation of nitrogen gas to ammonia) in lakes. It is hard to control blue-green algae because nitrogen fixation provides a reliable source of nitrogen.

Phytoplankton usually follow a seasonal succession whereby diatoms and sometimes golden algae are prevalent in spring, followed by green algae in late spring and early summer, and then blue-green algae in summer. If the lake turns over in the fall (i.e., lake mixes from top to bottom caused by cooling waters and wind), there is oftentimes a short-lived bloom of diatoms, blue-green algae, or dinoflagellates (Wetzel 2001, 358).

Nitrogen and Phosphorus Cycles. Runoff from the watershed results in the addition of nitrogen and phosphorus to surface waters. Inorganic nitrogen is transported in surface water runoff in both the dissolved and particulate forms. Groundwater inflow is also an avenue of transport of dissolved inorganic nitrogen. Atmospheric deposition adds nitrogen to surface waters. Nitrogen is abundant as nitrogen gas, but to be usable to plants and animals, it must first be converted to nitrate and other usable forms through the nitrogen cycle processes (USEPA 1999). These processes are detailed in the following paragraph.

The nitrogen cycle consists of nitrogen fixation, ammonification, nitrification, and denitrification. Nitrogen-fixing organisms, such as blue-green algae, convert nitrogen gas into un-ionized and ionized ammonia. Nitrogen fixation can comprise a large percentage of the annual total nitrogen inputs (> 80%) in an eutrophic or hypereutrophic lake with high phosphorus loadings and no phosphorus limitations on blue-green algae growth (Wetzel 2001, 209). Ammonification occurs when amino acids, a product of the decomposition of wastes and organic tissues by decomposer organisms, are oxidized to ammonia ions, water, and carbon dioxide (USEPA 1999). Nitrification is a two-step process involving two different sets of microorganisms. In the first step, *Nitrosomonas* microorganisms oxidize ammonia ions to nitrite and water. These bacteria can tolerate temperature ranges of 1-37° C and grow optimally at pH 7 (Wetzel 2001, 216). In the second step, *Nitrobacter* microorganisms oxidize the nitrite ions to nitrate. These bacteria are less tolerant of low temperatures and high pH (Wetzel 2001, 216). Nitrate must be converted to

[10] The littoral zone is the area from the shoreline region between the highest and lowest seasonal water levels to the greatest depth at which rooted plants occur (Wetzel 2001, 131-132).
[11] Algae that grow on macrophytes.
[12] Zooplankton are microscopic animals that feed on algae and are consumed by fish.

ammonium by nitrate reductase before it is in the bioavailable form. Through denitrification, nitrates are reduced to gaseous nitrogen by facultative anaerobes[13] (USEPA 1999).

Phosphorus is not abundant in the aquatic environment under natural conditions and is usually the nutrient limiting biological productivity[14]. Orthophosphate is the most important form of inorganic phosphorus because it can be used directly by algae. Soluble reactive phosphorus (SRP) includes orthophosphate. Total phosphorus is the measurement of both organic and particulate forms (which are not bioavailable) and soluble reactive phosphorus (which is bioavailable). A large percentage of phosphorus in fresh waters is in the organic phase (Wetzel 2001, 241). Organic phosphorus is converted to phosphate in the sediments primarily by the break down of organic matter by bacteria.

Phosphorus sorbs to soil particles and organic matter and is transported to surface waters via eroded sediments. Phosphorus can become unavailable as it sorbs to particles and the bottom substrate of lakes and reservoirs. As the bottom layer of a lake or reservoir becomes anoxic, phosphorus can desorb from sediments and recycle back into the water column. Also, bottom dwellers such as carp can disturb the bottom layer, causing phosphorus to be released from the sediments into the water column. Algae, including both microscopic and attached forms, and bacteria take up soluble reactive phosphorus, mainly as orthophosphate, and convert it to organic phosphorus. These algae and bacteria are in turn consumed by zooplankton, which excrete some of the organic phosphorus as SRP. Plants and animals then take in the SRP and the cycle begins again (USEPA 1999).

Phosphorus is deposited in lake bottom sediments via five different pathways: sedimentation of phosphorus minerals transported from the surrounding watershed; adsorption or precipitation of phosphorus with inorganic compounds; allochthonous[15] organic matter sedimentation of phosphorus; autochthonous[16] organic matter sedimentation of phosphorus; and, algal and macrophyte uptake of phosphorus from the water column and subsequent deposition to the sediments as detritus (Wetzel 2001, 245-246).

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[13] Organisms that can live in the presence or absence of oxygen.
[14] The limiting nutrient is usually nitrogen or phosphorus and it is the nutrient that when not available in sufficient quantities limits plant growth. A ratio of nitrogen to phosphorus of less than 7:1 in water is usually nitrogen limited and ratios greater than 10:1 are indicative of phosphorus limited water bodies (USEPA 2000b).
[15] Organic matter created within the watershed and imported to the water body (Wetzel 2001, 49)
[16] Organic matter created within the water body (Wetzel 2001, 49)

The following sections (Sections 2.1-2.2) outline the applicable water quality standards and evaluate the data that were used to place Big Bear Lake on the 1994 303(d) list for nutrients and noxious aquatic plants. Creek data are discussed separately and are contained in Appendix A. Additional data that were collected after Big Bear Lake was placed on the 1994 303(d) list are also evaluated. Finally, a new set of data was collected beginning in 2001 as part of the TMDL Task Force monitoring. Although there were extensive nutrient data already present and BBMWD regularly collected nutrient samples and depth profiles, there were data gaps that needed to be filled. These gaps arose in part because of the varying analytical methods and detection limits, analytes and sampling locations that had been used in the various investigations of lake and tributary water quality conducted to that time. These variations made data comparison and interpretation difficult. It was recognized that there was a need to collect phosphorus data utilizing lower detection limits, to analyze for ammonium, orthophosphate, and chlorophyll *a* on a regular basis, and to collect data from representative areas within Big Bear Lake and the watershed at a regular interval. These data are also evaluated and compared to the applicable water quality standards.

2.1 Applicable Water Quality Standards

The beneficial uses of Big Bear Lake as identified in the 1995 Water Quality Control Plan for the Santa Ana River Basin (Basin Plan) are as follows:

- Municipal and Domestic Supply **(MUN)**
- Agricultural Supply **(AGR)**
- Groundwater Recharge **(GWR)**
- Water Contact Recreation **(REC1)**
- Non-contact Water Recreation **(REC2)**
- Warm Freshwater Habitat **(WARM)**
- Cold Freshwater Habitat **(COLD)**
- Wildlife Habitat **(WILD)**
- Rare, Threatened or Endangered Species **(RARE)**

The beneficial uses of Rathbun Creek as identified in the Basin Plan are as follows:

- Municipal and Domestic Supply **(MUN)**
- Groundwater Recharge **(GWR)**
- Water Contact Recreation **(REC1)**
- Non-contact Water Recreation **(REC2)**
- Cold Freshwater Habitat **(COLD)**
- Wildlife Habitat **(WILD)**

The beneficial uses for Grout Creek as identified in the Basin Plan are as follows:

- Municipal and Domestic Supply **(MUN)**
- Groundwater Recharge **(GWR)**
- Water Contact Recreation **(REC1)**
- Non-contact Water Recreation **(REC2)**
- Cold Freshwater Habitat **(COLD)**
- Wildlife Habitat **(WILD)**
- Spawning, Reproduction, and Development **(SPWN)**

The beneficial uses for Summit Creek as identified in the Basin Plan are as follows (all are **intermittent** beneficial uses):

- Municipal and Domestic Supply **(MUN)**
- Groundwater Recharge **(GWR)**
- Water Contact Recreation **(REC1)**
- Non-contact Water Recreation **(REC2)**
- Cold Freshwater Habitat **(COLD)**
- Wildlife Habitat **(WILD)**

The Basin Plan specifies the following narrative and numeric water quality objectives for inland surface waters that pertain to nutrient impairment:

> Algae: "Waste discharges shall not contribute to excessive algal growth in inland surface receiving waters."
>
> Nitrate: " Nitrate-nitrogen concentrations shall not exceed 45 mg/L (as NO3) or 10 mg/L (as N) in inland surface waters designated **MUN** as a result of controllable water quality factors."
>
> Un-ionized ammonia (UIA)[17] for COLD (most restrictive):
> Acute (1-hour) objective = 0.822[0.52/FT/FPH/2]
> Chronic (4-day) objective = 0.822[0.52/FT/FPH/RATIO]
> (Please see the 1995 Basin Plan pp. 4-5 and 4-6 for an explanation of FT, FPH and RATIO)
>
> Dissolved oxygen (DO): "The dissolved oxygen content of surface waters shall not be depressed below 5 mg/L for waters designated **WARM**, or 6 mg/L for waters designated **COLD** as a result of controllable water quality factors. In addition, waste discharges shall not cause the median dissolved oxygen concentration to fall below 85% of saturation or the 95th percentile concentration to fall below 75% of saturation within a 30-day period."

[17] The UIA objectives specified in the Basin Plan have not been approved by the USEPA. The USEPA recommends that these objectives be reviewed and revised based on the USEPA's revised national ammonia criteria. A review of the UIA objectives was included on the Regional Board's 2002 Triennial Review list.

The Basin Plan also specifies site-specific nutrient numerical water quality objectives for Big Bear Lake. These are as follows:

- Total phosphorus -- 150 µg/L
- Total inorganic nitrogen (TIN) [18] -- 150 µg/L

No site-specific numeric nutrient objectives have been established for the Big Bear Lake tributaries.[19]

2.2 Assessment of Existing Conditions Relative to Numeric and Narrative Water Quality Objectives

This section describes conditions in the Big Bear Lake watershed that resulted in the inclusion of Big Bear Lake as nutrient impaired on the 1994 303(d) list (Table 2-1). Nutrient data that were evaluated and compared to the objectives for Big Bear Lake as part of the initial TMDL problem identification were the data collected in 1994 by the Regional Board as a follow-up to the Clean Lakes Study (Table 2-2), data collected from 1994-2000 by the BBMWD (Table 2-3), and data collected from 2001-2003 by the TMDL Task Force (Table 2-4). For all datasets, Big Bear Lake data are compared to the Basin Plan Objectives specified above. Data that exceed the Basin Plan Objectives are noted in the respective table for each dataset. See Appendix A for tabulation of creek data.

Total Phosphorus, TIN, Nitrate as N, Un-ionized ammonia. The nutrient-related data used to place Big Bear Lake on the 1994 303(d) list were collected as part of a Clean Water Act Section 314 grant (Clean Lakes Study) titled, "Investigation of Toxics and Nutrients in Big Bear Lake." (Courtier and Smythe 1994). The data were collected between April 1992 and April 1993 (Table 2-1).

Table 2-1. Nutrient concentrations (µg/L) for Big Bear Lake (April 1992-April 1993)

	Total P	**Total N**	**TIN***	**UIA-N (chronic)**	**NO3-N**
Average	47	1220	236	NA	66
Median	40	1250	100	NA	23
Number of samples	18	18	18	18	18
Number of non-detects	2	0	NP	NA	13
Max	120	2200	650	NA	470
Basin Plan Objective	**150**	**NA**	**150**	**Varies with pH/Temp**	**10**
Number of samples equal to, or exceeding BP Objective	0(0%)	NA	4(22%)	4(22%)	0(0%)

One-half of the detection limit for non-detects was used to calculate the descriptive statistics
*TIN is calculated from the sum of nitrate, nitrite and ammonia individual values
NA = not applicable
NP = no detection limit provided

[18] TIN is the sum of nitrate, nitrite, and ammonia forms of nitrogen. Staff believes that total nitrogen rather than TIN is the parameter of concern (See Section 3.0, Numeric Targets for detailed discussion).
[19] The numeric objectives specific to Big Bear Lake do not apply to the lake's tributaries via the tributary rule, only the narrative objectives specified in the Basin Plan apply (Vassey 2004).

Data from 1994 were also used to assess nutrient quality in the lake. Data for Big Bear Lake are compared to the Basin Plan Objectives and values that exceed those objectives are shown in Table 2-2.

Table 2-2. Nutrient concentrations (µg/L) for Big Bear Lake (May 1994)

	Total P	**Total N**	**TIN***	**UIA-N (chronic)**	**NO3-N****
Average	43	1333	756	NA	--
Median	40	1450	725	NA	--
Number of samples	4	4	4	4	4
Number of non-detects	0	0	NP	NA	4
Max	70	1800	1525	NA	--
Basin Plan Objective	**150**	**NA**	**150**	**Varies with pH/Temp**	**10**
Number of samples equal to, or exceeding BP Objective	0(0%)	NA	3(75%)	2(50%)	0(0%)

*TIN is calculated from the sum of nitrate, nitrite and ammonia individual values.
** Statistics not provided as all samples were non-detect
NA = not applicable
NP = no detection limit provided

Data collected by the BBMWD from 1994-2000 were also evaluated against the TP, TIN, nitrate and un-ionized ammonia chronic objectives in the Basin Plan (Table 2-3).

Table 2-3. Nutrient concentrations (µg/L) for Big Bear Lake (BBMWD:1994-2000)

	Total P	**Total N**	**TIN***	**UIA-N (chronic)**	**NO3-N****
Average	37	818	10	NA	--
Median	25	800	0	NA	--
Number of samples	144	178	178	24	104
Number of non-detects	135	1	NP	23	104
Max	750	1800	500	NA	--
Basin Plan Objective	**150**	**NA**	**150**	**Varies with pH/Temp**	**10**
Number of samples equal to, or exceeding BP Objective	3(2%)	NA	3(2%)	NC	0(0%)

One-half of the detection limit for non-detects was used to calculate the descriptive statistics.
*Only 11 samples out of 178 had a concentration above 0 µg/L. TIN was calculated as the difference between TN and TKN (ammonia was below detection limits).
**Statistics not provided as all samples were non-detect.
NA = not applicable
NP = no detection limit provided
NC = not calculated because temperature was not recorded

TMDL Monitoring Program

Starting in June 2001, a program of monthly nutrient monitoring at four main lake stations and seven tributary stations was initiated as part of the nutrient Total Maximum Daily Load (TMDL) process and is presently ongoing. Originally, ten lake stations were monitored but after February 2002, only four main lake stations (Dam (#1), Gilner Point (#2), Mid Lake Middle (#6), and Stanfield Middle (#9)) or MWDL1, MWDL2, MWDL6, and MWDL9 were monitored due to limited funds (Figure 2-1). Data from June 2001 through Oct. 2003 is included in the analysis for these four main TMDL stations (Table 2-4). At all ten stations a photic zone[20] composite water column sample and a discrete bottom water column sample were analyzed for total nitrogen, total dissolved nitrogen, ammonia-N, nitrate + nitrite-N, total phosphorus, total dissolved phosphorus and orthophosphate-P. Chlorophyll *a* was analyzed in the photic zone composite samples since algae need light to grow. As shown in Table 2-4, these data were evaluated against the nutrient objectives. Please refer to Appendix A for tributary data summaries.

[20] Photic zone is the zone to which light can penetrate the water column. For the purposes of this monitoring, the photic zone is calculated as two times the secchi depth.

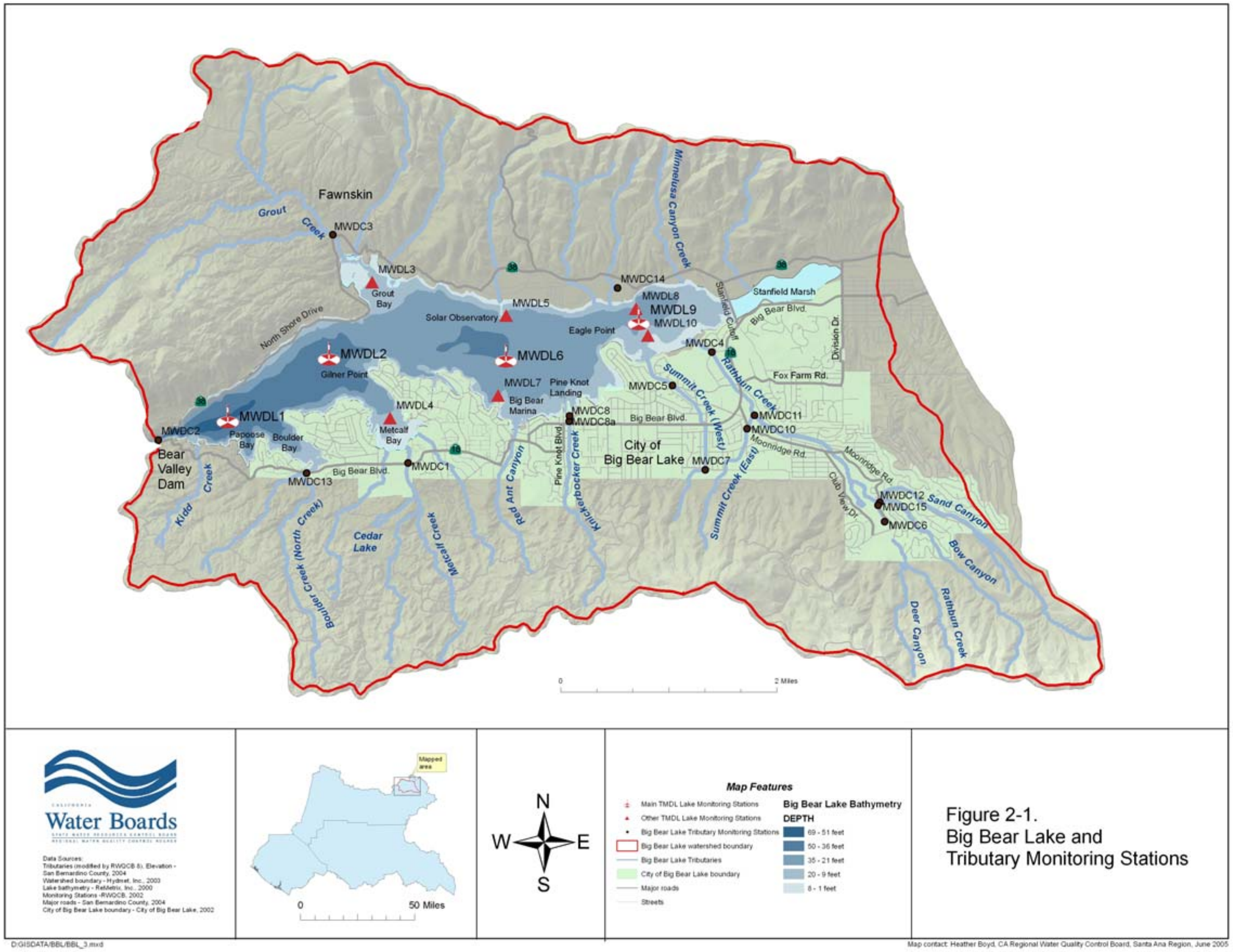

Figure 2-1.
Big Bear Lake and
Tributary Monitoring Stations

Table 2-4. Big Bear Lake nutrient water quality data summary (June 2001- October 2003)

	Ortho-P	**Total P**	**Total Dissolved P**	**Total N**	**Total Dissolved N**	**Nitrate+Nitrite as N**	**Ammonia as N**	**Chlorophyll a**	**TIN**	**UIA-N (chronic)**
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	mg/m^3	µg/L	
Minimum	0.2*	8	6	883	756	0.1*	4	1.5	4	--
Maximum	113	182	118	2211	1490	57	586	96.7	593	--
Median	5*	54	20	1210	959	4*	38	15.3	47	--
Mean	9*	61	24	1259	988	9*	74	17.6	82	--
Std. Dev.	14*	35	16	243	140	12*	94	13.9	95	--
25^{th} percentile	2*	37	16	1061	893	2*	17	9.9	18	--
75^{th} percentile	9*	71	26	1413	1070	10*	87	21.8	107	--
# of data points	250	250	249	250	249	250	250	126	250	250
Detection Limit	3	2	2	4	4	5	3	2.0	--	--
Basin Plan Objective	**NA**	**150**	**NA**	**NA**	**NA**	**10****	**NA**	**NA**	**150**	**Varies with pH/Temp**
Number of samples equal to, or exceeding BP Objective	NA	9(4%)	NA	NA	NA	0(0%)	NA	NA	35(14%)	5(2%)

TIN = Total inorganic nitrogen – calculated by summing the individual values of ammonia and nitrate+nitrite, no detection limit provided -- note that the TIN summary statistics do not equal the sum of the nitrate+ nitrite as N and ammonia as N summary statistics because all summary statistics were based on individual values (e.g., the max nitrate + nitrite as N and max ammonia as N did not occur on the same sampling date, so the max TIN does not equal the sum of these two maximum values).
NA = Not applicable
Statistics not calculated for UIA-N (chronic).
* Estimated using both the robust probability plotting method and by the (parametric) maximum likelihood method adjusted for bias (Helsel and Cohn 1988).
**Note that the Basin Plan Objective is for Nitrate-N.

Noxious aquatic plants. Big Bear Lake was also identified on the 1994 303(d) list as impaired due to noxious aquatic plants. Big Bear Lake is eutrophic, as demonstrated by the proliferation of nuisance aquatic plants, primarily Eurasian Watermilfoil (*Myriophyllum spicatum* L.) and Coontail (*Ceratophyllum demersum* L.). Eurasian watermilfoil is listed as a state noxious weed in several states, including California (USDA 2003). Eurasian watermilfoil is a rooted submersed plant, found in waters from 1 to 15 feet in depth. As stems reach the water surface, they branch out and form dense canopies that shade out other vegetation. It is a perennial that overwinters by root crown and is spread by runners and fragments (Aquatic Plant Management Society 2002b; USCOE 2002). Coontail is a submersed free-floating (rootless) plant, found in waters 1-20 feet deep. It provides an important habitat for aquatic organisms and is found in standing water. It is an evergreen perennial and a prolific seed former. Coontail is usually not considered a major nuisance plant. However, in certain habitats it can become the dominant species, crowding out other species. It also forms a dense mat and can affect boating and other recreational activities on the lake (Aquatic Plant Management Society 2002a; USCOE 2002).

Eurasian watermilfoil was introduced to Big Bear Lake sometime in the 1970s and since that time has become a major nuisance, impairing the beneficial uses of the lake, including contact water recreation (REC1), non-contact water recreation (REC2), warm (WARM) and cold (COLD) freshwater habitat and wildlife habitat (WILD). Through mapping, (ReMetrix 2001, 4), it was determined that approximately 781 acres of Big Bear Lake were impacted by macrophyte growth at that time, primarily by Eurasian watermilfoil. Eurasian watermilfoil can grow up to one foot per week and reach the surface from depths of over 20 feet deep, if the light conditions are suitable (ReMetrix 2001, 1). It can outcompete the more beneficial species of aquatic plants in the littoral zone of Big Bear Lake, changing the species composition, and impacting the aquatic environment. Low dissolved oxygen or anoxia may develop below the Eurasian watermilfoil canopies. Eurasian watermilfoil serves as both a sink and source of nutrients. Nutrients are taken up from the sediment by the roots and stored in the plant's tissues. As the plants age and die, nutrients are released back into the water column (Smith and Adams 1986). In addition, Eurasian watermilfoil photosynthesis can raise the pH in the water column, which allows phosphorus to be released from the sediments.

Hydroacoustic data collected by ReMetrix in 2002 and 2003 (ReMetrix 2004) and analyzed by Tetra Tech (2004a) show that the greatest density of plants in Big Bear Lake is found at depths less than 10 feet, as shown in Table 2-5. Depending on the average lake level, the average suitable plant habitat area at depths less than 10 feet ranges between 500 and 600 acres for the entire lake area (Tetra Tech 2004a). Fluctuations in lake levels affect the areas of the lake less than 10 feet in depth; thus, the area that is suitable for macrophyte growth (Figure 2-2). For example, the east end segment[21], as delineated in the WASP model (see Section 5), has more suitable area for growth in 1999 than 2003. This same effect is observed in the shallow bay segments (e.g., Metcalf Bay and Grout Bay) because these areas are much shallower than the rest of the lake. So, if the average deficit from full pool in 1999 was approximately 3 feet versus nearly 14 feet in 2003, then any areas less than 14 feet deep in 2003 would be dry and not able to support macrophyte growth. Similarly, areas that were previously too deep to support macrophyte growth in 1999 became shallower from 1999-2003 and were then able to support macrophyte growth in areas that never had any macrophytes.

[21] Ten segments were used in the WASP model effort (see Section 5).

Table 2-5. Macrophyte average percent biovolume for depth intervals in surveyed segments

Depth (feet)	Boulder Bay	Metcalf Bay	Grout Bay	Main Bay	East End	Rockwall	Papoose	Average
avg <3		40.0		80.0	60.0			60.0
avg3-4	49.0	5.7		27.8	66.5		16.0	33.0
avg4-5	67.7	60.0		11.0	72.9	34.5	18.7	44.1
avg5-6	11.8	7.7	23.7	14.0	13.8	12.2	14.9	14.0
avg6-7	6.7	5.6	5.9	13.2	0.9	15.8	16.5	9.2
avg7-8	13.7	7.8	15.8	23.6	1.0	16.4	16.8	13.6
avg8-9	14.1	8.8		9.0	1.6	10.5	18.0	10.3
avg9-10	13.5	7.2		6.2	0.4	4.9	16.7	8.2
avg10-12	11.7	3.6		1.6	0.1	2.7	7.8	4.6
avg12-15	4.7	0.5		3.3	0.1	2.1	2.7	2.2
avg15-20	0.1	0.0		2.7	0.0	0.1	0.2	0.5

Source: Modified from Tetra Tech 2004a
Note: Raw 2002, 2003 data provided by ReMetrix 2004

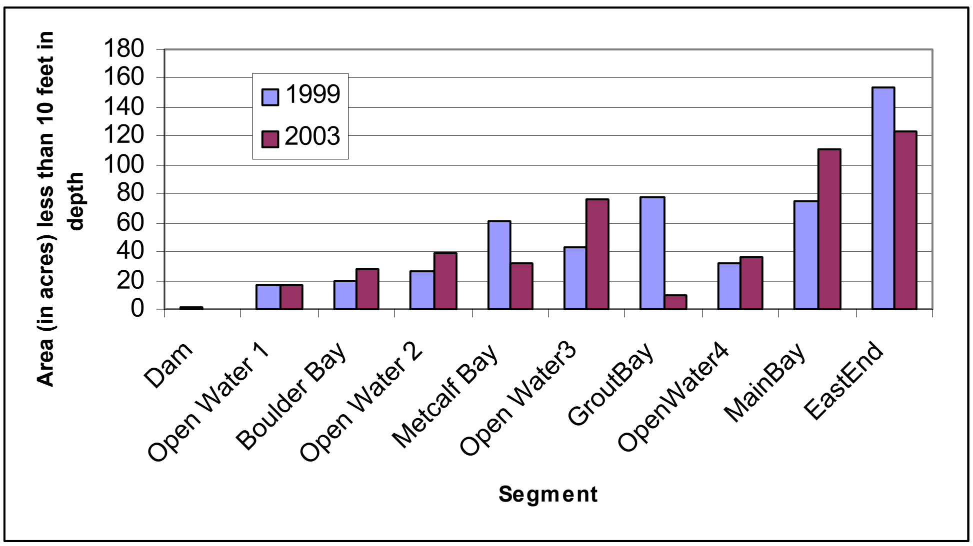

Figure 2-2: Effect of two different lake levels (1999 avg. lake level = 6740.15 feet, 2003 avg. lake level = 6729.58 feet) on macrophyte growth in areas less than 10 feet deep for the 10 segments defined in the WASP model (see Section 5) (Source: Modified from Tetra Tech 2004a)

The BBMWD has had an aquatic plant harvesting program for years, but according to recent data, harvesting is able to control only approximately 240 acres of the 781 total acres of submersed aquatic plants. In addition, because Eurasian watermilfoil grows up to one foot per week, many areas impacted by this noxious plant must be harvested more than once per season (ReMetrix 2001, 14). According to the BBMWD's records, approximately 86% of the weed cutting occurs around private docks, and the other 14% occurs where navigational hazards need to be removed or where public access needs to be improved. Eurasian watermilfoil comprises approximately 73% of all the macrophytes harvested, coontail comprises 20%, and the remaining 7% is a combination of other types (BBMWD 2002a). Shown in Figure 2-3 is a map depicting the distribution of aquatic macrophytes as observed by ReMetrix (2001). Table 2-6 is a list of all the aquatic plants that BBMWD has identified in Big Bear Lake (BBMWD 2002a).

Table 2-6. Aquatic plants present in Big Bear Lake

Common Name	Scientific Name	Type of Macrophyte
Curlyleaf pondweed	*Potamogetan crispus*	Rooted, submersed
Leafy pondweed	*Potamogetan foliosus*	Rooted, submersed
Eurasian watermilfoil	*Myriophyllum spicatum* L.	Rooted, submersed
American elodea	*Elodea canadensis*	Rooted, submersed
Coontail	*Ceratophyllum demersum* L.	Free floating, submersed
Smartweed	*Polygonum hydropiperoides* Michx.	Rooted, submersed
Sago Pondweed	*Potamogeton pectinatus* L.	Rooted, submersed
Widgeon grass	*Ruppia maritime*	Rooted, submersed
Spikerush	*Eleocharis spp.*	Emergent

Source: BBMWD 2002a

Harvesting is not a preferred control of the nuisance aquatic plants, since this approach can spread Eurasian watermilfoil fragments to other areas of the lake and can impact the bottom biota. It can also resuspend bottom sediments into the water column, contributing to the internal loading of nutrients and decreasing water clarity. Harvesting, however, also removes plant biomass, which can improve dissolved oxygen concentrations and reduce impacts to recreational and other beneficial uses. Other noxious aquatic plant removal methods besides mechanical methods include chemical, biological, and physical methods. All methods have advantages and disadvantages (Madsen 2000).

BBMWD obtained an NPDES permit in 2002 (Order No. R8-2002-0028, NPDES No. CA8000396) to apply Sonar, an aquatic herbicide, to selected parts of Big Bear Lake to aid in the eradication of Eurasion watermilfoil. BBMWD also applied Sonar again in 2003 with some funding provided by a Clean Water Act Section 319(h) nonpoint source pollution grant. Order No. R8-2002-0028 was rescinded upon adoption of Order No. R8-2004-0007 (NPDES No CA8000396), which incorporates the addition of alum as well as Sonar to Big Bear Lake.

Sonar, which contains the active ingredient fluridone, is a systemic herbicide. This means that the herbicide is absorbed by the plant leaves and stems and moves to the actively growing areas of the plant, killing the entire plant. Sonar works by disrupting the formation of carotenoid pigments that are necessary for the plant to photosynthesize. The targeted plants die and decompose slowly. Usually, plants do not grow back for over a year, if the treatment is effective. Sonar at very low concentrations can be used to target Eurasian watermilfoil, but these concentrations must be closely monitored for the herbicide to work (Getsinger et al., 2002). Data collected and summarized by ReMetrix and BBMWD show a large reduction in plant biovolume and noxious aquatic plants (BBMWD and ReMetrix 2004) subsequent to Sonar application.

Vegetation stabilizes the sediment from resuspension and erosion by reducing wave activity. If all macrophytes within a lake are removed then higher turbidity in the water column might be observed due to more frequent occurrences of sediment resuspension. Sediment resuspension can have many negative effects on a lake's water quality, such as enhanced nutrient recycling, reduced water transparency, and excessive nuisance algal growth (Getsinger et al. 2002). Therefore, it is important that more of the beneficial species of aquatic plants in Big Bear Lake recolonize. Ideally, the lake would have a balanced composition of aquatic plant species, with no one aquatic plant forming a monoculture. In turn, this diversity of habitat would also support a diverse wildlife community.

Algae. Although algae is not one of the pollutants identified on the 1994 303(d) list as responsible for impairment in Big Bear Lake, nutrient enrichment often causes algal blooms. For this reason, data pertaining to algae are evaluated with respect to the nutrient listing for Big Bear Lake. Chlorophyll *a*[22] is an estimator of algae biomass.

According to many lake professionals, if the total P concentration in the water column is > 10 µg/L and/or the total nitrogen concentration in the water column is approximately 150 µg/L, blue-green algal blooms during the growing season can be expected (USEPA 2000b). Reviewing the phosphorus and nitrogen water column data for Big Bear Lake summarized in Table 2-7, Big Bear Lake would be expected to have such blue-green algal blooms. Big Bear Lake does experience algal blooms, but there are few written reports detailing their time and place. Researchers with the California Department of Fish and Game noted blue-green algae blooms during early May and summer to fall during their studies in the fall of 1976 through the fall of 1978 (Siegfried et al. 1978, 35; Siegfried and Herrgesell 1979b, 16-31). Also, on October 7, 1992, there was a newspaper article about a major algae bloom in Big Bear Lake (Atwood 1992). There have been some accounts of blooms in September 2000 as well (personal observation). For the most part, Big Bear Lake has experienced few problems with excessive algae. This could be because Big Bear Lake has an overabundance of macrophytes, and researchers have noted that either macrophytes or algae seem to dominate in a lake system, not both. If algae are abundant, the formation of algal mats can shade out light, inhibiting the growth of macrophytes; if macrophytes are abundant, algae appear not to grow (USEPA 2000b). In addition, the proliferation of coontail, a free-floating macrophyte that obtains nutrients from the water column, might also compete significantly with algae for nutrients in the water column. The other macrophytes observed in the lake are rooted and obtain their nutrients from the sediment. The limited algae problems in the lake could be due to the presence of a healthy zooplankton population that grazes on phytoplankton (Anderson et al. 2004). It should be noted that algal blooms have become more prolific and chlorophyll *a* values have increased from 2002 to 2003, probably as a result of the Sonar applications and removal of macrophytes, making more nutrients available for algae growth.

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[22] Total chlorophyll measures all the molecules of chlorophyll, including *a, b, c*, and *d.* Chlorophyll *a* is the primary pigment involved in photosynthesis and is most often the form of chlorophyll measured.

Table 2-7. Annual median concentrations of total N and total P in Big Bear Lake

Agency	Year	Total N Median (µg/L)	No. of samples	Total P Median (µg/L)	No. of samples
RWQCB	1992	1250	16	40	16
RWQCB	1993	955	2	25	2
RWQCB	1994	1450	4	40	4
BBMWD	1994	800	31	<50	14
BBMWD	1995	700	45	25	36
BBMWD	1996	800	37	<50	30
BBMWD	1997	700	15	<50	15
BBMWD	1998	600	8	95	8
BBMWD	1999	1000	11	25	11
BBMWD	2000	920	31	25	31
BBMWD/RWQCB[1]	2001	1196	40	57	40
BBMWD/RWQCB[1]	2002	1054	91	39	91
BBMWD/RWQCB[1]	2003	1352	119	64	119

[1]Medians calculated using both photic and bottom samples from Lake stations 1, 2, 6, and 9
½ the detection limit was used for non-detect values; <50 = all samples less than non-detect at 50 µg/L

Several researchers collected and analyzed algae samples in Big Bear Lake during the late 1960s (Pearson and Irwin 1972, 32-36); the 1970s (Irwin and Lemons 1974, 32-35; Siegfried et al. 1978, 30-35; Siegfried and Herrgesell 1979b, 16-25) and more recently, during 2002, as part of the TMDL Task Force monitoring (BBMWD 2002b) and 2003 (Anderson et al. 2004). The early researchers collected algae samples at multiple locations in Big Bear Lake during different seasons of the year. Overall, they found that diatoms were dominant during the early spring, green algae were dominant during the early summer, and blue-green algae were dominant during midsummer-fall. Phytoplankton analyses of samples collected on August 7, 2002, from the west end (MWDL1) and the east end (MWDL9) of Big Bear Lake showed that more than 50% of the total phytoplankton population was from the taxon Cyanophyta (blue-green algae), specifically *Anabaena circinalis* (58.8% of the total density for MWDL9) and *Microcystis aeruginosa* (55.5% of the total density for MWDL1). *Anabaena*, along with a few other genera of blue-green algae, dominate nitrogen fixation in lakes (Wetzel 2001, 207). There is a spatial gradient in phytoplankton densities, with the east end exhibiting much greater densities (more than three times) than that of the west end. This is likely the result of the generally westerly winds characteristic of the Big Bear Lake area, which transport algae from west to east. Anderson et al. (2004) also observed the most dominant algal group present in Big Bear Lake was that of cyanophytes (*Anabaena, Anacystis*, and *Microcystis*), followed by chlorophytes (*Eudorina*, *Pediastrum*, *Oocystis, Staurastrum* and *Scenedesmus*).

Chlorophyll *a* concentrations, which are used as an estimator of algae biomass, greatly increased during the late summer in all years (2001-2003). This appears to correlate with the senescence and decay of the macrophytes and the release of phosphorus, supporting phytoplankton growth. There is a trend of increasing chlorophyll *a* concentration from the western part of the lake to the east (Table 2-8).

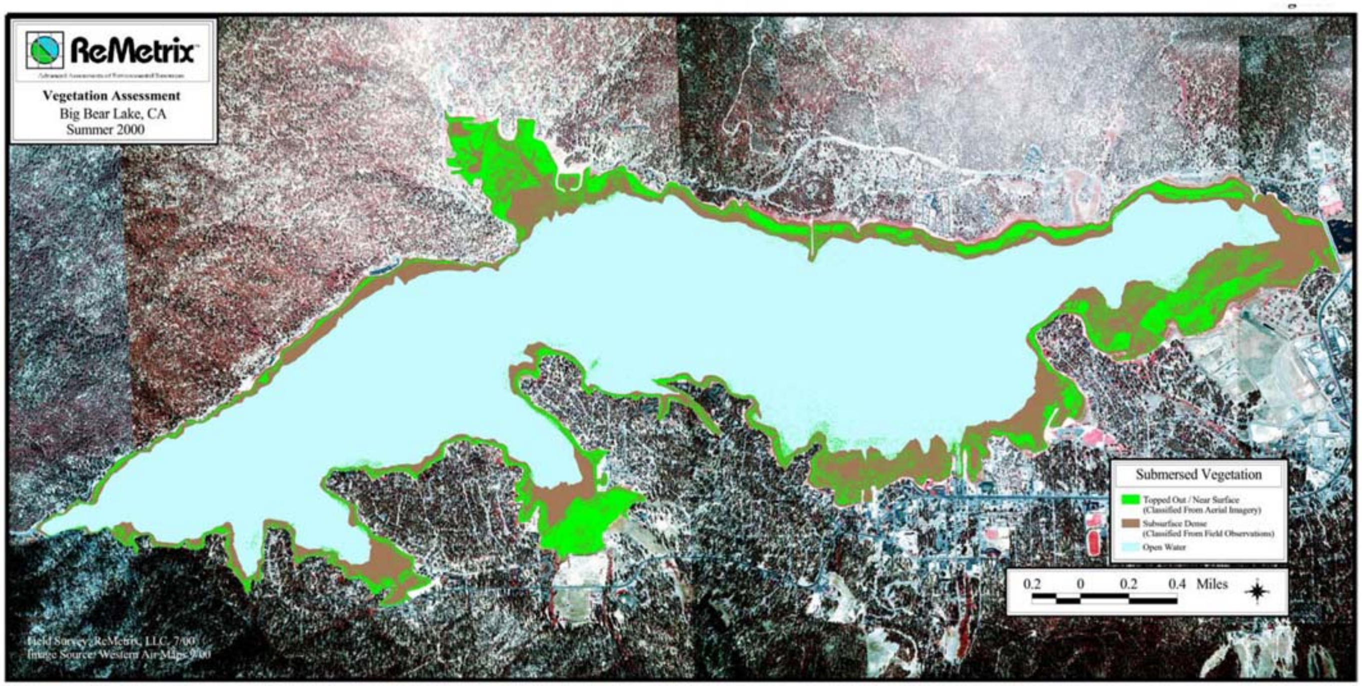

Figure 2-3. Map of near-surface and submerged dense vegetation, as analyzed using aerial photography collected in 2000.

Table 2-8: Chlorophyll *a* growing season averages (GS) and medians for 2001, 2002, and 2003 in mg/m^3 (equivalent to µg/L)

	TMDL Lake Station				
	MWDL1	**MWDL2**	**MWDL6**	**MWDL9**	**All stations**
GS Average 2001	10.3	10.5	16.8	31.9	17.4
GS Average 2002	13.6	12.0	18.6	33.5	19.4
GS Average 2003	12.2	15.0	19.7	33.1	20.0
Average for all 3 years	**12.2**	**12.9**	**18.7**	**33.0**	**19.2**
GS Median 2001	10.9	11.5	16.2	28.6	13.9
GS Median 2002	14.2	12.1	21.8	21.8	18.0
GS Median 2003	13.0	13.9	18.9	29.1	16.4
Median for all 3 years	**13.0**	**13.3**	**17.1**	**28.5**	**15.2**

Note: Growing season is defined as the period from May 1- Oct. 31

Dissolved Oxygen. Although Big Bear Lake is not on the 303(d) list as impaired due to low dissolved oxygen levels, nutrient enrichment often causes low dissolved oxygen concentrations. Anoxic conditions in the lake bottom allow the release of inorganic phosphorus and ammonia from the sediments, contributing to the internal loading of nutrients. For these reasons, data pertaining to dissolved oxygen are evaluated with respect to the nutrient listing.

As plants die, the dead plant matter (detritus) settles to the lake bottom and starts to decay. This process consumes oxygen and can result in anaerobic conditions in the lake bottom or hypolimnion. Plants respire both day and night. At night, respiration occurs but not photosynthesis. Respiration consumes oxygen and can result in oxygen depletion. With a prolonged decrease in oxygen at the lake bottom, the benthic community can change from aerobic organisms to anaerobic organisms. Oxygen depletion can also aid in the release of ammonia and phosphorus from sediments as the sediment -water interface becomes anoxic. As dead organic matter is broken down, un-ionized ammonia can also be produced. Depending on pH levels and temperature, this form of ammonia is toxic to fish. Massive beds of nuisance aquatic plants (e.g., Eurasian watermilfoil) can also outcompete more beneficial species of aquatic plants by reducing light penetration and shading out other vegetation types. These large mats of nuisance aquatic plants can also increase temperature and pH and decrease dissolved oxygen concentrations, which in turn affects the fishery.

Data collected as part of the TMDL Task Force Monitoring Program through the end of 2003 show that dissolved oxygen concentrations stratify during the middle of June and that the stratification continues throughout the end of July. Stratification is pronounced at the west end stations (MWDL1, MWDL2) and middle station (MWDL6). Although the lake does not experience long periods of thermal stratification, the stratification that occurs is enough to lower dissolved oxygen concentrations in the deepest parts of the lake during summer (Figure 2-4). The east end station (MWDL9) is generally well-mixed and experiences less pronounced dissolved oxygen stratification (Figure 2-5). The east end has an abundance of macrophytes and is shallower; both of these conditions are most likely the reasons that the east end does not experience more extreme, persistent low dissolved oxygen conditions. These measurements, however, were obtained from mid-morning to early afternoon when dissolved oxygen concentrations would be at their maximum. If vertical profiles were obtained in the early a.m., it is likely that the east end would experience very low dissolved oxygen concentrations due to the effects of respiration from the abundance of macrophytes. The results agree with those from previous researchers who have noted that dissolved oxygen stratification takes place primarily during the months of June, July, August and September (Pearson and Irwin, 1972, 7; Siegfried et al. 1978, 15-16). Dissolved oxygen levels fall below the Basin Plan Objective for Inland Waters (see Section 2.1) in all seasons, but primarily during the summer months (Table 2-9) and at depths greater than 11 meters (Table 2-10). Higher dissolved oxygen concentrations occur at the shallower east end of the lake during summer. Courtier and Smythe (1994) and Siegfried et al. (1978, 15) reported similar results.

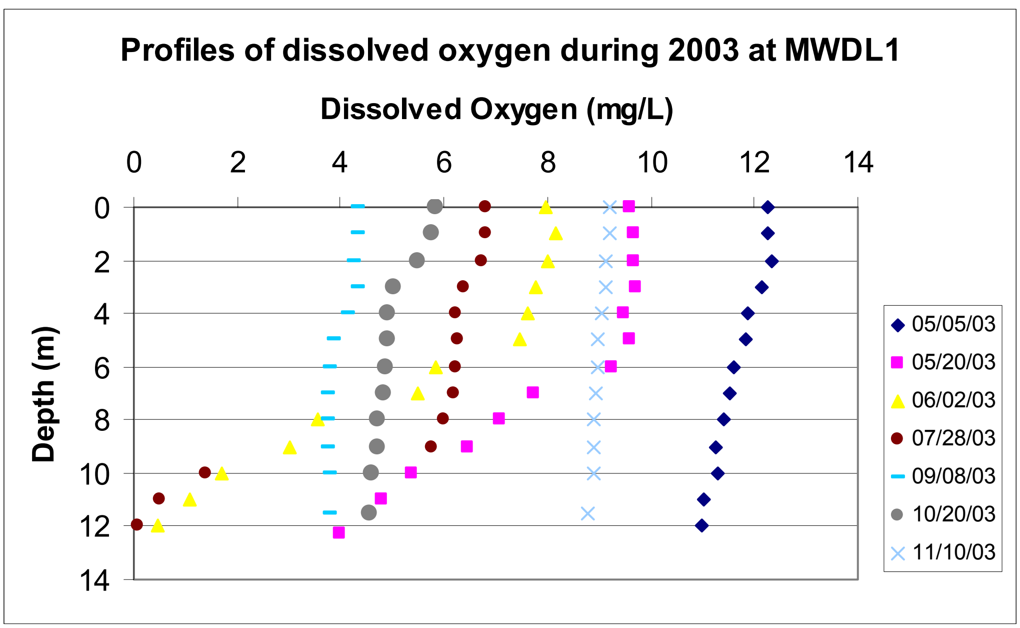

Figure 2-4: Dissolved oxygen profiles for MWDL1 (west end) during 2003

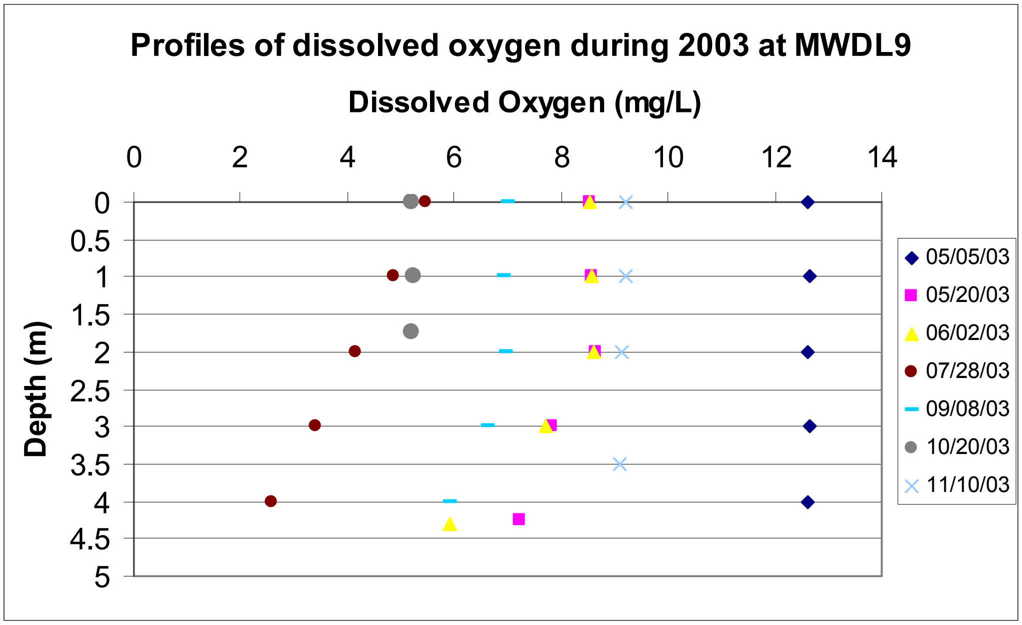

Figure 2-5: Dissolved oxygen profiles at MWDL9 (east end) during 2003

Table 2-9. Seasonal effects on compliance with the COLD dissolved oxygen objective – percentage of samples exceeding COLD dissolved oxygen objective

Season	Year		
	2001	2002	2003
Jan - March	NA	3%	0%
April - June	20%	5%	17%
July - Sept	32%	12%	43%
Oct - Dec	10%	0%	27%

NA = not applicable – sampling did not start until June 2001
Note: Results from all stations (1,2,6,9) combined

Table 2-10. Depth effects on compliance with the COLD dissolved oxygen objective

Depth	Percentage of samples exceeding COLD dissolved oxygen objective
0-5 meters	8%
6-11 meters	33%
>11 meters	78%

Note: Results from all stations (1,2,6,9) and all years (2001-2003) combined. East end station (MWDL9) is only represented by 0-5 meters.